A

PRACTICAL TREATISE

ON THE

CONSTRUCTION AND FORMATION

OF

RAILWAYS.

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PRACTICAL TREATISE

ON THE

CONSTRUCTION AND FORMATION

OF

RAILWAYS,

SHOWING THE

PRACTICAL APPLICATION AND EXPENSE

OF

EXCAVATING, HAULAGE, EMBANKING, AND PERMANENT WAYLAYING;

ALSO, THE METHOD OF

FIXING ROADS UPON CONTINUOUS TIMBER BEARINGS;

INCLUDING THE PRINCIPLES OF ESTIMATING

THE GROSS LOAD AND USEFUL EFFECT PRODUCED BY MECHANICAL OR OTHER MOTIVE POWER,

UPON A LEVEL AND UPON ANY INCLINATION.

ILLUSTRATED WITH

DIAGRAMS AND ORIGINAL USEFUL TABLES.

BY JAS. DAY,

Author of The Railway Calculator, or Engineers' and Contractors' Assistant, &c. &c.

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MDCCCXXXIX.

[ENTERED AT STATIONERS' HALL.]

ERRATA.

PAGE 21, last line, *for* fifth, *read* sixth.

Page 89, commencement of line 5, (from bottom) *b* omitted.

Page 161, lines 18, 19, *for* right side of the opposite drawing, *read* left side of the lower drawing.

Page 170, column "36 feet," line 14 from bottom, *for* 2623, *read* 3623

Page 187, line 2, *for* Table 3, *read* Table 4

... give a practical exposition of that now popular and all-absorbing subject—RAILWAYS, a medium of internal communication which, with all its concomitants and appendages, the British Nation has brought so rapidly forward to their present comparative state of perfection.

The WORK will be found devoid of all algebraical formulas; but it will illustrate familiarly the

A

INTRODUCTION.

It is presumed that the following pages require a very brief preface. The writer would merely observe that, as the opinion of several judicious friends coincided with his own; namely, that a work of this nature was yet greatly wanted, and as he has enjoyed very considerable experience during the last ten years in the direction and execution of important railway-works; he has been induced to make the present attempt, with strong hopes of success and approbation.

The object of the Work is to give a practical exposition of that now popular and all-absorbing subject—Railways, a medium of internal communication which, with all its concomitants and appendages, the British Nation has brought so rapidly forward to their present comparative state of perfection.

The Work will be found devoid of all algebraical formulas; but it will illustrate familiarly the

PRACTICAL APPLICATION in every department of every thing essential and expedient, during the formation of railways, with a view both to their thorough SCIENTIFIC CONSTRUCTION and ultimately PERMANENT MAINTENANCE after completion.

Throughout the entire volume the author has endeavoured to treat separately the several kinds of works; their nature, material, stages, and processes; so that each subject may be at once connected and distinct, and the *whole* rendered equally clear and compendious. In some instances perhaps this may have led him into a little prolixity: if so, the candid reader is respectfully entreated to attribute it solely to a strong desire of avoiding any ambiguity.

The TABLES it is hoped will be of great utility, not only as a medium of general reference, but of abridging tedious calculations: it was deemed advisable to give copious examples illustrating their use; likewise, in some instances, the method by which they had been calculated; in order that even a tyro might understand their principle, and those fully conversant with the subject see immediately how the results had been obtained.

The greatest attention has been bestowed in preparing the several Tables for the press, and in the revision of the proof-sheets; and the author

confidently expects that no errors have been overlooked.

Scarcely venturing to anticipate what might be the extent of his success, the writer was originally induced only to publish a limited number of copies; but, upon more mature consideration, it was thought advisable to submit the sheets already printed, and also the remainder of the MS. to the perusal of some professional gentlemen,—of course, to persons equally if not more conversant with the subject than the writer himself. After undergoing this probation, he is proud to add that, they were returned not only with the approval of judges so competent, but with their unsolicited offers to become subscribers to the work: the latter has indeed been since unhesitatingly shown to many individuals connected more or less with railways; and from the warm encouragement received, the writer determined to issue a second edition forthwith; even before the completion of the first. This "plain unvarnished tale" will, it is hoped, be perfectly satisfactory with regard to the period of time which has elapsed since the work was originally announced.

Hetton-le-Hole, Durham, July, 1839.

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PRACTICAL TREATISE

ON

THE CONSTRUCTION AND FORMATION

OF

RAILWAYS, &c.

CHAPTER I.

INTERNAL COMMUNICATION.

Primeval state of Society—Improving the natural resources of a Country—Ancient Canals, &c.—Count Platon's description of passing rapids in Sweden—Policy of the Romans in establishing roads—Roman roads, and system of making them—Wooden railroads—British, Scotch, and Irish Canals—Facilities of railroads—Resistance to the motion of carriages on railroads, and boats on canals—Advantages and disadvantages of canals—Performance of horses on railways and canals—Turnpike-roads—Interest for the capital invested in railways—Railways improving the land contiguous to them—Impositions practised upon railway companies, &c. &c.

In a rude state of society, we may reasonably infer, that man would have little either to barter or to dispose of; consequently, at that period, any other mode of conveyance than that of his own animal power, was unregarded; and we have presumptive evidence, which will scarcely admit of a doubt, that the improving the natural resources of every country has been both the cause and effect of civilization: they have, therefore, invariably progressed simultaneously.

We may also conjecture, that as civilization exercised its benignant influence on man, his wants would become augmented; and further, that a great part of the product of his industry would be an unprofitable superfluity, until he exchanged a portion of it, for that of his neighbours, and ultimately for that of other nations. Hence we find, at the earliest era, man inhabiting the shores contiguous to lakes and rivers, where his frail bark afforded him a species of conveyance, of which the Indian canoe, and Welch river coracle, are admirable specimens. Such, it is obvious, would be the incipient progress of society.

"Let us travel over all the countries of the earth," says the Abbé Raynal, "and wherever we find no facility of travelling from a city to a town, or from a village to a hamlet, we may pronounce the people to be barbarians."

The acquisition gained by a nation in ameliorating the internal communications of their country, it is premised, is unquestionable, and will be admitted by every political economist. Whether such national improvements are acquired through the instrumentality of individuals, philanthropically or sordidly, we shall not stop to inquire; as, in numberless instances, pecuniary motives, in their ulterior consequences, have produced the general interest and benefit of mankind.

It would appear from history, that the earliest operations of any magnitude, (magnitude in its most comprehensive sense, considering the then incipient state of society) for improving the natural internal communications of a country, happened fortuitously, by making hydraulic works, for the purposes of agriculture, and which were subsequently found to afford the means of an inland navigation. Such

appears to have been the case with the Deltas of the Nile, in Egypt; and the estuaries of the Po, the Rhine, and the Rhone, on the continent of Europe, and many other places.

What length of time elapsed between the making of these simple canals for the purpose of irrigation and drainage, and the ascertaining that they possessed the means of transporting commodities from one place to another, is uncertain; but we are given to understand by Herodotus, in his book Euterpe, that in the reign of Mœris, or five hundred years before the Trojan war, a rise of eight cubits inundated the Delta, so as to be *navigable for boats*, excepting the small artificial eminences whereon the towns stood. The same author says, a canal was drawn from the Nile above the city of Bubasto; that it passed around a mountain from the west to the east, and afterwards turned south to the Red Sea. He attributes its commencement to Necos, the son of Psammaticus, 616 B. C.; but gives its completion to Darius Hystaspes, 521 B. C. It was four days' navigation, and four *ships* could pass abreast.

Strabo agrees with Herodotus; and says it was one hundred cubits in breadth, with depth sufficient to carry large vessels, (lib. i. and xvii.) He adds, that it terminated at the Arabic Gulf; and that in his time, the merchants of Alexandria found an outlet from the Nile in the Arabic Gulf, to go to India. And Omar-ebn-el-Kattab ordered Amrou, who had conquered Egypt, about the year 635, to open the canal from the Nile to Quotzoum, on the Red Sea, to *convey the contributions in corn* into Arabia. Elkmaim informs us, that it was shut up again by the Caliph Abugia, or Almanzor, in the year 773.

We are also informed, that in China, about 264 B. C. the Prince Tsin-chi-koang, on account of the wars and works he undertook, and the great consumption of his capital, made his subjects carry, night and day, from place to place, many million sacks of grain, so that they were made beasts of burden. But that Han, who began to reign in 202 B. C. caused *canals to be made, to carry rice and other grain*, from the provinces to the capital, so that all porterage was abolished; but it was not till 86 B.C. that these great works were completed. But the Great, or Imperial Canal in China, from the capital at Pekin in the north, to the city of Canton, in the southern part of the empire, reckoned a distance of about 920 miles, Duhalde says, that it is *not* continued to Pekin, in order that the porterage may *employ* the great population of that quarter!

So far back as the middle of the fourteenth century, we read of some magnificent hydraulic works having been executed, even in the remote regions of India. In the district called the Punjab, or country of five rivers, artificial canals were constructed, chiefly by Feroze III. about 1351, and who persevered in making these improvements for 37 years. "The country between Delhi, upon the Jumnah (a branch of the Ganges) and the Punjab on the Indus, being frequently without water, this prince undertook to furnish a supply for the purposes of agriculture and *inland navigation;* he therefore built the city of Hipai Ferozeh, about one hundred miles west of Delhi, and caused two canals to be drawn to it. He had previously made a canal from the Jumnah, near the northern hills, to Sufidoon, a royal hunting-place. This canal was full sixty miles in length; it passed by Canawl

and Joglickpoor; and was about four yards in breadth. He afterwards extended it to Hipai, his new city, when it was altogether 114 miles long. About 1626, Shah Ischan made clear out that part which reaches from the hills to Sufidoor, and made a new canal from thence to Delhi, which is about 60 miles."

The other principal canal was from the river Sutlege to the city of Hipai Ferozeh, thus mentioned in Ferushta, translated by Dowe:—"He (Feroze) drew a canal from the Cagger, passing the walls of Sirsutti, and joined it to the river Kera, upon which he built a city, named after himself, Ferozabad; this city he watered with another canal from the Jumnah; those public works were of prodigious advantage to the adjacent countries, by supplying water for their canals, and a commodious *water-carriage* from place to place." Besides these canals connected with Ferozabad, "there are similar works adjacent to Lahore on the S. E. bank of the river Hydroates of Alexander. This noble river has its source in the mountains near Nagerkote; it enters the plains near Shapoor, or Rajapan; and it is from this place the canal of Shah Nehr has been carried a distance of about 73 miles, to supply the city of Lahore with water."

It is stated, that by the latter end of July, all the lower parts of Bengal, contiguous to the river Ganges and Burrampooter, are overflowed; and form an inundation more than 100 miles in length, nothing appearing but villages and trees; and that "it is calculated that dykes of above 1000 miles in length, have been constructed, to protect one particular district. One branch of the Ganges, navigable only during rainy seasons, is conducted 70 miles between two of those dykes; and, when full, passengers look down upon the country."

We shall close this section of our historical department, with Count Platon's description of the novel and dangerous mode of passing rapids, on the rivers in Sweden, Norway, and Finland, which cannot fail to be interesting.—"Very light and tender boats, of from 20 to 24 feet in length, containing from three to five men, run down the middle of the stream with incredible velocity. It produces a sensatiom impossible to be described, when, from a steep rock on the shore, one sees the boat approaching the cataracts, two men pulling in the usual way with oars, and the pilot, who is appointed and sworn for this business, steering at the helm, also with an oar. He, particularly, is not to be disturbed by any thing whatever: his look is steady and penetrating; and even his hair, on both sides his head, is tied fast behind his neck, lest it might, by the motion of the wind, or by his rushing through the air, wave before his eyes. The moment he reaches the edge of the fall, he animates his companions to pull with all their strength, in order to give his boat sufficient way for the action of the steerage; he then rushes down the tremendous current, between steep rugged shores, and isolated masses of rocks, in the midst of the falls, and is frequently hid from the spectator by the foaming of the broken roaring water; in a moment he reappears, running with incredible velocity right against a perpendicular rock, with all the probability of instant destruction, increased by his cries to augment the velocity by fresh efforts; when, in the very last moment, as the boat seems touching the rock, he casts it in a quite different direction, often at an angle of 90 degrees, and again disappears in the next curve of the stream. The whole of these operations is an affair of an instant, scarcely to be measured by time."

The Romans, having previously learned from the Carthaginians the art of making paved roads, would, in all probability, be the first who introduced any regular roads into Great Britain; as the aborigines, at the time of the invasion by Cæsar, were merely barbarians, living chiefly upon what they procured from the chace. The grasping policy of the Romans, it is apparent, was, after the subjugation of the inhabitants, to lay the country open by those roads, to facilitate the transport of troops and supplies, in order to keep them in a state of subjection. "The Roman roads," says Mr. Tredgold, "were made so firm and solid, that they have not entirely yielded to the dilapidations of fifteen centuries. These roads, he states, ran nearly in direct lines; natural obstructions were removed or overcome by the efforts of labour or art, whether they consisted of marshes, lakes, rivers, or mountains. In flat districts, the middle part of the road was raised into a terrace. In mountainous districts, the roads were alternately cut through mountains, and raised above the valleys, so as to preserve either a level line, or a uniform inclination. They founded the road on piles, where the ground was not solid; and raised it by strong side-walls, or by arches and piers, where it was necessary to gain elevation. The paved part of the great military roads was 16 Roman feet* wide, with two side ways, each 8 feet wide, separated from the middle way by two raised paths, 2 feet each."

The following account of the construction of those Roman roads, is translated from the French Encyclopædia, article *Chemin*, and shews that this enterprising people only wanted a knowledge of steam, and its application as a motive power, toge-

* "The English foot is to the Roman foot as 1000 is to 967."

ther with a knowledge of the modern system of manufacturing iron, to have adopted Railways. "They were commenced everywhere by two furrows measured by a string, these parallel lines deciding the width of the road; the intervening space was then excavated, and in this depth the several layers of the road-materials were laid, the first being as cement of chalk and sand an inch thick. On this cement, as a first coat, broad and flat stones, six inches high, were placed one on the other, and connected by a very strong mortar; as a second coat, followed a thickness of eight inches of small round stones, softer than the pebble, intermixed with tiles, slates, and the fragments of buildings, all worked to an adhesive substance; and, as a third coat, a thickness of a foot of cement, made from rich earth, mixed with chalk. These interior substances formed a road from three feet to three and a half feet thick; and upon this was placed an entire surface of gravel, bound by a cement with a mixture of chalk. This crust is still to be found perfect in several parts of Europe."* Indeed, there are some remains of those Roman roads yet visible in Britain. At the city of Chester, the Castrum of the Romans, remnants of the old Roman pavement are frequently discovered, when the superincumbent soil, several feet deep, has been removed. In Scotland, a portion of Roman causeway may still be seen leading from Musselburgh Bay to the Firth of Forth.

With the exception of these Roman roads, and the carriages employed thereon, "the width of the wheel-tracks not being more than three feet,"† (and

* Abstract of the report of Jos. Gibbs, Esq. addressed to the London, York, and Norwich committees of the Great Northern Railway Co. as inserted in the *Railway Magazine* for Oct. 1835.

† Rondelet, as cited in Tredgold, 2nd edit. p. 7.

perhaps even those carriages were exclusively, or mostly, devoted to the purposes of war (it appears that the whole of the internal communication of Great Britain was, for centuries afterwards, effected by the employment of what were termed "pack-horses," carrying their loads upon their backs, the roads being similar to sheep-tracks. Even at the present time, we find in the mountainous districts of Wales, and in the Highlands of Scotland, that the greater part of their commodities are transferred from one place to another, by this mode of conveyance.

From the works we have quoted in the succeeding chapter, it will be seen, that the next improvement in interior communication, was in substituting wooden railroads for the common or military roads; but as that species of road is noticed there at greater length, it is here merely adverted to, in chronological order.

Canals.—"The total number of canals in Great Britain (says Mr. Herbert) is 103; the total exent 2688 miles; and the capital sunk in their construction is computed at upwards of thirty millions sterling." Although those works are now prosecuted to so great an extent, the following pages will show that after the art had been introduced by the Romans, that it soon became obsolete, and was never revived to any extent, until the middle of the last century. Consequently, the above length of canal navigation was executed in about 80 years.

"The Foss Dyke canal, supposed to have been originally made by the Romans, and restored under Henry I. is connected with the Witham at Lincoln. At Braybrook Mere it proceeds on one level 11 miles, to the bank of the river Trent at Forksay, about eight miles above Gainsborough. It is preserved at the same level by a lock, having gates

pointing in both directions. This is the oldest artificial canal in England; but we are uncertain in what manner it was anciently connected with the Trent, or even that it did ever form such a connection."

"The Car Dyke, which skirts the uplands from the river Nene at Peterborough, to the Welland near Market Deeping, and from thence by Bourne and Billingham to the river Witham near Lincoln. It is a very ancient work, probably Roman. Its position leads us to think it has been a catchwater drain, but it might also be used for the purpose of navigating through this great extent of country."

In Scotland their appears to have been a canal made across the island, along Scotia's Great Glen, from near Inverness on the east, to the Sound of Mull on the west, at a very remote period: but it would seem only to have been subservient to the purposes of contention and warfare. The passage alluded to runs thus:—"This extraordinary pass [the great glen] has excited public attention even since the time of the Romans. In the curious map by Richard of Cirencester, (composed in the fourteenth century, and founded chiefly on Ptolemy's Tables,) a continued canal is represented along the whole of the valley between the east and west seas. Of this, perhaps, the most ancient of existing maps, a correct copy is inserted in the able memoir which accompanies Mr. Arrowsmith's excellent map of Scotland."

The first attempt at canal-making in England, in modern times, was in forming the Sankey brook into a canal, in the year 1755,—from the river Mersey to near St. Helen's in Lancashire, but which was not completed until five years afterwards.

The Duke of Bridgewater's celebrated canal, completed under the direction of the indefatigable Brindley, is well deserving of attention, it being inestimable, as the prototype of canal navigation in England. The original destination of this canal was to convey coals from the Duke's mines at Worsley, to the town of Manchester, and for which the act of 32 George II. was obtained; two other acts were subsequently granted for extensions and alterations. "In 1795, by an act 35 George III. an extension was made from Worseley Mill to the town of Leigh, in Lancashire, with a branch to Chat Moss. Excepting 82 feet of rise by ten locks, in the distance of 600 yards, at Runcorn, the whole of the navigation, which is about 45 miles, is upon one level, to which, when we add 18 miles of the Grand Trunk from Preston Brook, making 63 miles, besides what is underground, in the Worsley coal-mines, which cannot be less than 10 miles, we have the extraordinary extent of 73 miles of canal navigation upon one level. Combined with this advantage, we may add, that the Grand Trunk, and all the canals at Manchester, connected with the western sides of the ranges of mountains which separate Lancashire and Yorkshire, finally discharge water into the Duke's canal, and thereby insure a superabundant supply for all its purposes."

We shall now present the reader with a cursory view of some of the principal canals executed in Great Britain and Ireland. The first that we shall advert to, is the Grand Trunk, or Staffordshire Canal, which forms a communication between the Trent and the Mersey; and thus connects the German Ocean with the Irish Sea. From the eastern commencement of this canal, to its junction

with the Duke's at Preston Brook, is 93 miles, and, including its (Grand Junction) branches, will make a total length of canal navigation of 160 miles.

Leeds and Liverpool Canal.—The western commencement of this canal is at the river Mersey, near the latter place; and its other terminus is in the Aire and Calder navigation at Leeds; a total distance of 130 miles. The rise from low water in the Mersey to the canal basin, is 52 feet; and thence to the summit, near Colne, is 431 feet: from the summit, to the eastern termination of the canal, the fall is 410 feet. The locks are for boats 70 feet long, with 14 feet beam; and the depth of water in the canal is 54 inches. The great tunnel of Foulridge is 1630 yards long, 18 feet high, and 17 feet wide.

The Lancaster, or Northern Canal, commences near Wigan, and proceeds north, passing Garstang, Lancaster, &c. crossing the river Ribble and valley in its course, and terminating at Kendal in Westmoreland. Its length is about 76 miles, 42 of which are upon one level. Near to Lancaster, the navigation is conveyed over the river Lune, by an aqueduct of 217 yards in length, containing five semicircular arches of 70 feet span. The piers are 30 feet in height, and supported upon piling; they (the piers) are 27 feet in breadth at the bottom, and diminish by regular offsets to about half that breadth at the springing of the arches. The total height of masonry upon the piling is 80 feet.

The Thames and Severn Canal is 109 miles in length, from where it commences in the river at Staines, to its termination at Lechlade, on the confines of Berkshire and Oxfordshire, where it crosses the central ridge of the island, by the great Sapperton tunnel of two and a half miles in length,

and then descends into the Stroud-water canal, in Gloucestershire; the latter navigation communicating with the river Severn, and ultimately with St. George's Channel. The locks upon it are in general 120 feet long, by 18 feet wide; and the depth of water in the canal is 46 inches.

Grand Junction Canal.—The general route of this undertaking is north-west through a part of the counties of Middlesex, Hertford, Buckingham, Bedford, and Northampton. The main line is 95 miles in length, and its branches nearly 30, making a total length of about 125 miles. The canal commences in the Thames, at Brentford; and its northern terminus is at Northampton, where a branch, 5 miles in length, is made up to that town. It passes through Blisworth and Braunston tunnels; the former being one and three quarter miles long, 18 feet high, and 16½ feet wide; and the latter, 2045 yards in length, containing a sectional area similar to that of Blisworth. The canal is 12 yards in breadth at the top of the water, 8 at the bottom, and contains a depth of water of 4½ feet. The locks are 85 feet in length, and their width 14 feet 6 inches.

The Ellesmere Canal, in Shropshire, is also deserving of especial notice, as containing some works of very great magnitude. This stupendous undertaking, by means of a large aqueduct and embankment, is conveyed across the romantic valley of the river Dee, at Pontcysylite, near the bottom of the celebrated valley of Llangollen. The aqueduct is 1000 feet and upwards in length, and 127 feet in height above the surface of the river Dee. It consists of nineteen segmental cast iron arches upon stone piers. The span of the arches is 45, and their versed sine, or height, 7 feet. The

centre piers, at the level of the surface of the river, are 12 feet in breadth; and the whole diminish regularly to 7½ feet, at the springing line of the arches. The embankment is 500 yards in length, and 75 feet in height, at the end contiguous to the aqueduct. At Chirk, the navigation is carried along an aqueduct of 200 yards in length, and 65 feet in height, from the bottom of the ravine to the bed of the canal; it contains ten semicircular arches of about 45 feet span; and from the foundation of the main piers to the top of the parapets, the height is 90 feet.

Scottish Canals.—At the eastern extremity of Aberdeenshire, commences the extraordinary Valley of Glenmore, or the Great Glen of Scotland. The eastern portion, for about 80 miles from Kinnaird's Head to where it contracts at Fort George, is termed the Murray Firth; and for about 12 miles to Inverness is also tideway. From thence across the island to Fort William, on the shore of Loch Eil, (an arm of the Western Ocean) the valley is formed by two parallel ranges of very high mountains, the bottom of which is occupied by an almost continuous line of lakes, nearly from sea to sea.

"Considering the facilities afforded by the lakes, and that it was desirable to accommodate the trade between the western parts of England and Scotland, and all Ireland; the eastern coast of Britain, the Baltic, and East Country; and also, between the east coast of Scotland and the West Indies; and likewise to pass small ships of war, Mr. Telford recommended, and the Board [for constructing the Caledonian canal] adopted a canal upon a large scale, viz. 120 feet wide at the water surface, 50 feet at the bottom, and 20 feet depth of water: the

locks of 170 and 180 feet of length, and 40 feet wide; these dimensions being sufficient, both in single and united locks, to admit of the largest vessels trading between Liverpool and the Baltic, the average of West Indiamen, and a 32-gun frigate when fully equipped."

The eastern extremity of the Caledonian Canal is connected with the tideway in the sheltered bay of Loch Beauly. To have 20 feet of water on the lower sill at high water, in ordinary neaps, (which rise there about 8 feet, and ordinary springs about 14 feet) it was necessary, from the flatness of the shore, to place the tide-lock about 400 yards from high-water mark. From this lock the canal is formed by artificial banks, until it reaches high-water mark at Clachnacarry, where another lock is placed upon hard ground. Immediately to the south of this, there is a basin, or floating dock, of 967 yards length, and 162 breadth, with a wharf at the upper end, for the trade of Inverness and the adjacent country. At the southern extremity of the basin, is a public road bridge; and adjacent to it, four united locks, each 180 feet long, and 40 feet wide, which, together, raise the canal 32 feet. From the top of these locks, the navigation is carried through a small lake, to Loch Ness, a beautiful sheet of water about 22 miles in length, from 1 to 1½ miles in breadth, and having a depth varying from 5 to 126 fathoms. At the south end of Loch Ness, stands the fort and village of Fort Augustus. On the northern side of the fort, the canal leaves the lake, crosses part of the glacis, and ascends 40 feet, by 5 locks. From thence it passes, by means of two locks, on to Loch Oich, which forms the summit level of this navigation, 94 feet above the tideway. The river, which flows through the ex-

tensive valley of Glengarry—passing through two lakes, one 10, and the other 6 miles in length—falls into Loch Oich, which insures an ample supply of water. Along the middle isthmus, there is some extensive cutting of 40 feet in depth, and also two locks, which carries the canal forward to Loch Lochy. From which lake, to the tideway at Loch Eil, the canal passes over a rugged surface, intersected by one considerable river and various small streams, all of which require aqueducts to pass the mountain torrents. Within one mile of the eastern extremity of Loch Eil, there are eight connected locks, of 180 feet in length each, and together descend 64 feet; from thence a level is continued to Corpach shore, where there are two connected locks, falling 15 feet, and one single sea-lock, falling 93 inches, which enters the tideway of Loch Eil, and forms the western terminus of the canal. From this haven, down Loch Eil, to the strait of Ardgower, a distance of 9 miles, the inlet is about a mile in breadth, at which latter place it contracts one half. Passing this strait onward, south-west, the inland navigation enters the Sound of Mull, where it falls into the general track of shipping, which passes by the Orkneys and Cape Wrath, and is therefore reckoned the western termination of this line of communication; which not only lessens the distance one half, but is free from the dangers and delays to which the above circuitous voyage, by the Orkneys, is subjected.

Forth and Clyde Canal.—This line commences at Grangemouth, on the river Carron, near its junction with the Forth, and passes by the west of Falkirk, to the eastern terminus of the summit level, a distance of 10 miles, having ascended 156 feet, by 20 locks; it then continues on this level to the

city of Glasgow; passing the Kelvin by an aqueduct of 150 yards in length, containing four segmental arches of 70 feet span. About 3 miles below Glasgow, a branch of 9 miles in length diverges to the Clyde, descending into the river by 19 locks. The distance between Grangemouth and its termination in the Clyde, is 35 miles.

The Union, or Edinburgh and Falkirk Union Canal, proceeds from Lock No. 16, or the fourth below the eastern terminus of the summit level of the preceding canal, and ascends 110 feet, by 11 locks; it then continues at this level for 30 miles, to the city of Edinburgh. The distance between the latter city and Glasgow, by this and the foregoing canal, is about 45 miles.

Irish Canals.—The principal lines of this species of communication in Ireland, are the Royal and Grand Canals. The former extends from Dublin, westward, to the Shannon; commencing on the north side of the Liffey, by a sea-lock 116 by 27 feet. "From thence the canal has 6 feet water, 24 feet bottom, and 44 width at surface; in 1½ miles it rises 62 feet, by 4 locks, to the broadstone level, where there is a large harbour for the use of the city. From thence, in 18½ miles, there is a farther rise of 175 feet, by 14 locks. The level is then 16 miles in length; then 8 locks, in 5½ miles, rise 70 feet to the summit level, which is 307 above the sea; this summit is 12 miles in length to Coolnahay, communicating by a navigable river at Mullingar, with Lough Owell, which is the chief reservoir for this navigation. From Coolnahay, the canal descends by 15 locks, in 22 miles, to the Shannon, Tarmonbarry, in the county of Longford."

The eastern terminus of the Grand Canal is in the Liffey, near its mouth; the canal passes near

the city of Dublin to James' Street harbour, and then proceeds westward to the Shannon near Bannagher. Including its branches to the river Barrow, and other places, comprehends in the aggregate a length of 100 English miles. Its route is nearly parallel to the preceding canal, and seldom 10 miles distant. The summit level is 240 feet above the sea, and 160 above the Shannon. There are 5 double and 29 single locks, between Dublin and Tullamore; 10 from thence to the Shannon. On the Barrow line, there are 10 single and two double locks. The dimensions of the canal are as follows:—width at bottom, 25 feet: at the water surface, 40 feet: depth, 72 inches, and 60 inches on the lock sills. Length of locks, 70 feet: width, 14½: and the average rise and fall 9 feet.

The foregoing account of the foreign canals is extracted from the Edinburgh Encyclopædia, art. Navigation Inland, where the reader will find an elaborate account of the internal communications of almost every country, there being upwards of one hundred quarto pages devoted to that subject; and which will well repay perusal. Part of the information relative to the English and Scotch canals, is from actual measurement, and the remainder from the standard work already named.

Canals having been constructed to such an extent during the last century, of course, ample time has elapsed to fully develope their capabilities. On the other hand, there was no railway executed, to develope the extraordinary latent resources of steam for the purposes of locomotion, until the great competition took place on that stupendous undertaking, the Liverpool and Manchester Railway, ten years ago. The latter mode of communication, therefore, can only be understood to be in a com-

parative state of embryo. Yet even in this condition, its superiority over floating conveyances is unquestionable, possessing, as it does, both facility and economy.

The following fact is singularly demonstrative, and will exemplify the extraordinary power already attained on railways in facilitating commerce.—"A gentleman left Manchester, in the morning, went to Liverpool, 30 miles off, purchased and took back with him to Manchester, on the railroad, 150 tons of cotton. This he immediately disposed of, and, the article being liked, an offer was made to take another such quantity. Off he starts again, and actually that evening delivered the second 150 tons, having travelled 120 miles, in four separate journies, and bought, sold, and delivered 30 miles off, at two distinct, consecutive deliveries, 300 tons of goods, in about 12 hours! We simply ask the opponents of railways, with their darling 'things as they are,' could they do so? We may indeed truly say, that, if the excellence of our common roads has been the body,—good, well constructed railroads will be the soul of our national prosperity." *Railway Magazine.*

It has been clearly demonstrated, that the resistance to the motion of carriages on railroads, increases, simply, as their volocity, while on fluids it increases as the square,—or, as some affirm, the cube of the volocity;—the resistance of the atmosphere equally effecting both modes of transit. Now, without wishing to disparage canals, on account of the, sometimes, long interruptions to which they are liable during winter, can we be surprised, when the law of resistance militates so much against speed in fluids, that, in this commercial nation, where time and certainty are of such primary importance, as to

be frequently preferred, even at an increased rate of tonnage, that canal navigations have been superseded by railroads, as principal means of internal communication throughout the kingdom,—indeed, almost throughout Europe!

Moreover, canals, on account of their peculiar construction—having either to be level, or a series of levels—do not admit of that efficacious applicability of ascent and descent, inherent to railways: especially if the traffic is all to be conveyed in one direction only, (of which kind of roads there are many,) and, where the gravitating force, when judiciously employed, decreases the cost of transit considerably, as will be subsequently explained.

But, in level districts, where the trade is *not* confined to time, probably the making of canals may still be resorted to, or for the passing of ships from sea to sea, yet they must always be limited to such locations, and uses; as the raising of boats to great changes of level, is, (as we have experienced,) both dilatory and expensive, and, pecuniarily considered, verges closely on prohibition; for, although on some of the canals previously enumerated, great altitudes are surmounted, it is only by an immense consumption of time, and expenditure of capital, with great sacrifice of revenue, that such summits are attained.

"When a very slow rate of travelling is considered, (observes Dr. Lardner,) the useful effects of horse power, applied on canals, is somewhat greater than the effect of the same power applied on railways; but, at all speeds above three miles an hour, the effect on railways is greater; and, when the speed is considerable, the canal becomes wholly inapplicable, while the railway loses none of its advantages. At three miles an hour, the per-

formance of a horse on a canal and a railway is in the proportion of four to three, to the advantage of the canal; but, at four miles an hour, his performance on a railway has the advantage, in, very nearly, the same proportion. At six miles an hour, a horse will perform three times more work on a railway than on a canal. At eight miles an hour, he will perform nearly five times more work."*

It is but fair to state, that, according to recent experiments, a great change has been effected, in the opinion of scientific men, relative to the resistance of fluids; that is to say, that at a certain velocity, the boat rises in the water, and a consequent diminution of immersion and resistance takes place. And, by the experiments of Col. Reid, it appears, that by shaping the vessel according to the rate that she has to ply, the resistance is still further reduced; but, how far these improvements are applicable in practice is yet to be ascertained.

Turnpike roads, as a means of conveyance, are yet, *sometimes*, preferable, either to railroads or canals, on account of the comparative trivial expense incurred in their formation. Hence a less quantum of tonnage suffices to repay the interest of the capital invested. It is estimated that there are upwards of 20,000 miles of turnpike road, and 100,000 miles of common hard roads, completed in England. There is, however, a wonderful difference of opinion relative to their construction; that is to say, between Mr. MacAdam, the popular road-maker, and others equally competent to form sound opinions; but such controversy being foreign to our present purpose, we shall not enter upon the subject.

In the latter part of the fifth chapter we intend

*The *Steam Engine*, 6th edit. p. 238

introducing some tables respecting the resistance to the motion of carriages upon different kinds of roads, with their corresponding expense of transit.

The subjoined extract, from the report quoted in the eighth page, is very conclusive with respect to the capital embarked in railroads being ultimately compensated. "It becomes a natural question, if the present turnpike roads are inefficient, and their income inadequate to their maintenance, what prospect does the introduction of railways give for a fair remuneration to those who embark their property in establishing them? Happily, the reply is simple, and easily understood by all. Friction and gravity are the great absorbents of the impulsive power employed on both railways and turnpike roads; and the original cost bestowed to render the railway nearly horizontal, and the introduction of the smooth and hard surface upon railways, instead of the soft gravel used for turnpike roads, reduce this gravity and friction to the least possible amount. The great difference of motive power, requisite to overcome the gravity and friction upon railways, and upon turnpike roads, constitutes a saving, which, of itself, will answer the question."

These important advantages of railways, were foreseen, some years ago, by Dr. Thos. Younge; for he concludes his notice of them in these remarkable words:—"It is possible that roads, paved with iron, may, hereafter, be employed for the purpose of expeditious travelling, since there is scarcely any; resistance to be overcome, except that of the air; and such roads would allow the velocity to be increased, almost without limit. *Nat. Phil.* vol. 1. p. 219, 1807.

It affords us great pleasure to be able to state, that the opinions entertained by many, respecting

the dreaded ill consequences of having railroads passing through agricultural districts, have proved groundless. And further, that it is now very rarely that we observe land, contiguous to railroads, whether near town, or in the country, advertised for sale, or to be rented; but the advantages consequent on its propinquity to the railroad, forms a prominent feature in each advertisement.

We may also mention, that the early prejudices, relative to the introduction of the railway system, are fast declining. We now scarcely ever read of a compensation case for land, coming before a jury, but the railway company come off victorious; indeed it is but just, after a company have made a liberal offer,—which is generally done in the first instance,—that it ought to be justly entertained, and not become subject to the exorbitant claims of any capricious landowner.

Various have been the schemes resorted to, to impose upon railway-companies, prior to their commencing operations: but the following unprecedented gross imposition, (of that kind) deserves recording, in order to remind us how careful we ought to be, when deliberating on the access and deterioration of land, caused by its severance. The case in question is extracted from Messrs. Lecount and Roscoe's graphic *Description of the London and Birmingham Railway*.

"In one portion of the line, on the Birmingham division, some land was passed through, in such a way, that it was evident the proprietor required, in reality, no accommodation in the way of bridges at all. At the first outset, however, he demanded five bridges; but, in the course of the discussion, came down to four, with an equivalent in the price of the land. It was absolutely necessary to obtain

the land, or the contractors would have been stopped in their operations, so that, after a great deal of argument, the company was forced to submit to this enormity, and the agreement was signed, sealed, and delivered, guaranteeing to the proprietor a bridge at A, another at B, another at C, and another at D.

"Soon after the money had been received, the proprietor wrote, to say, he thought he could dispense with a bridge at A, and if the company would give him about half its value, he would do without it; of course, as this would save expense, it was agreed to, and bridge A done away with; the proprietor receiving about half what it would have cost in building.

"When this quantity of hard cash had been a little time warming in his pocket, he discovered he could do without bridge B, and offered to commute that with the company, on the same terms as bridge A. This being agreed to, and paid for, he, in succession, found out that he could dispense with bridges C and D, on exactly the same terms; and thus every bridge, he had so pertinaciously demanded, were, one after the other, found to be totally unnecessary; as every body knew very well at first; but, it is to be supposed, that he found it a very agreeable way of getting a few cool hundreds; at any rate, such are the facts,—he has been paid for all the four bridges, none of which have been built."

We shall conclude the present chapter with another specimen from the same gentleman's work. "One rather original character sold to the company some land, and was loud and long in his outcries for compensation, ringing the changes on all sorts of damages which the railway could not fail of bringing upon him. Well, his demand was

paid, and his complaints were stopped. A few months afterwards, a little additional land was wanted from the same individual, when, surprising as it may appear, for some adjoining parts of this land so deteriorated by the railway, on which the company's works had brought such inevitable destruction, and for which reason so high a sum had been paid, he actually required a much larger price than was given him before; and, on the company expressing the surprise which was natural on hearing such a demand, he very coolly replied, "Oh, I made a mistake *then*, in thinking the railway would injure my property; it has increased its value, and, of course, you must pay an increased price for it.'"

CHAPTER II.

PROGRESS OF RAILWAYS.

Introduction of the principal of Railroads—"Way Leaves" introduced—Primary Railroads—Origin of "Single" and "Double-way"—Wooden Railroads—Invention of Cast and Malleable Iron Rails—Tram Roads—Cast Iron Edge Rails—Stone Blocks introduced—Malleable Iron square Bars—Malleable Iron Edge Rails—Railways, &c.

History informs us, that the principle of railroads, and the reducing of friction, was understood at a very remote period. At the memorable siege of Constantinople the genius of Mahomet conceived the bold design of transporting his lighter vessels by land for a considerable distance from the Bosphorus to the higher part of the harbour. "A level way," says Gibbon, "was covered with a broad platform of strong and solid planks; and to render them more slippery and smooth, they were anointed with the fat of sheep and oxen. Fourscore light gallies and brigantines, of fifty and thirty oars, were disembarked on the Bosphorus shore, arranged successively on rollers, and drawn forwards by the power of men and pulleys."

We shall now literally transcribe the descriptions given by our ancestors of some of the primary railroads, or as they have been aptly termed "British roadways," for it cannot but be interesting to know that those rude wooden railroads were the

original source from whence sprung those truly magnificent lines of inland transit now being ramified in almost every direction. Although it is extremely difficult to say from whom the idea of the railroad emanated, the honour of bringing it to the present comparative state of perfection, may, unquestionably, be ascribed to the British nation.

The precise date when railroads were invented, or first introduced into Great Britain, is rather involved in obscurity. It has been very justly remarked that in all probability they would be first introduced where the goods were of a certain description, the quantity considerable, and conveyed to one place only, and, we may probably add, not along roads of the best description; or, perhaps we may suppose that the laying down timber in the worst parts of the road to support the great weights continually being drawn upon it, suggested the idea of laying wooden rails the whole distance.

The great expense, in the north, incurred by leading coals from the pits to the place of shipment by common carts, or panniers on horseback—their only mode of conveyance until the year 1600—would, most likely, be where the railroad was first introduced into this island. A record, in the books of one of the free companies of Newcastle-upon-Tyne, dated 1602, states, "that, from tyme out of mynd, yt hath been accustomed that all cole-waynes did usually carry and bring eight baulls of coles to all the staythes upon the ryver of Tyne, but of late several hath brought only, or scarce, seven baulls."

It also appears that "way-leaves" were granted for the transit of coal two and a half centuries prior to the above date, but, of course, it would then be carried upon the backs of animals. "In every period of the history of coal mining in

the north, these 'way-leaves' have formed an important item of expenditure, or covenant. '*Sufficiens chiminum*' occurs in the latter sense, in a lease to the prior of Durham, in 1354. *Chiminum* is a term often met with, in grants of property to monasteries, and implies a right of road to or through the lands appropriated." *Fossil Fuel, the Collieries, and Coal Trade*, page 349.

In Gray's *Chorographia*, published at Newcastle, in the year 1649, the manner of conveying coals from the pits to the river Tyne is thus described. "Many thousand people are employed in this trade of coals: many live by working them in the pits: many live by conveying them in waggons and waines to the river Tyne." In the same work it is stated that Master Beaumont, a south country gentleman, "of great ingenuity and rare parts, adventured into our mines with his £30,000, who brought with him many rare engines not known then in those parts, as—the art to boore with iron rodds, to try the deepnesse and thicknesse of the coale; rare engines to draw water out of the pits; waggons with one horse to carry down coales from the pits to the staythes, to the river." From which it would appear that Mr. B. would probably be the first who introduced waggons and perhaps "waggon-ways," as they were then termed, into the north.

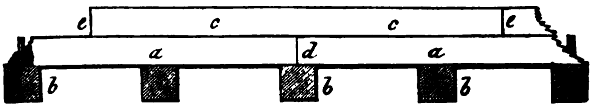
Lord Keeper Guildford, who was upon the northern circuit in 1676, thus describes the waggons and the waggon-ways—"The manner of the carriage is by laying *rails* of timber from the colliery to the river, exactly straight and parallel; and bulky carts are made, with rollers fitting those rails, whereby the carriage is so easy, that one horse will draw down four or five chaldron of coals, and is an immense benefit to the coal merchants."

The following description of the formation of railways is given in *Jaa's Voyages Metullurgiques*, in 1765.—"When the road has been traced, at six feet in breadth, and where the declivities are fixed, an excavation is made of the breadth of the said road, more or less deep, according as the levelling of the ground requires. There are afterwards arranged, along the whole breadth of this excavation, pieces of oak wood, of the thickness of four, five, six, and even eight inches square: these are placed across, and, at the distance of two or three feet from each other; these pieces need only be squared at their extremities; and upon these are fixed other pieces of wood, well squared and sawed, of about six or seven inches breadth, by five in depth, with pegs of wood; these pieces are placed on each side of the road, along its whole length; they are commonly placed at four feet distance from each other, which forms the interior breadth of the road."

This kind of road was termed the "single-way," but was very imperfect, and destroyed quantities of timber on account of breakage, after being partly worn by the wheels of the waggons, and the frequent perforations near the ends of the sleepers, in fastening down the rails. This destruction of timber, it may naturally be supposed, would cause many attempts at amelioration, and, probably, the addition of another rail upon the surface of that one which was fastened to the sleeper, was the next improvement, which was afterwards termed the "double-way."

Modern Wooden Railway.—The subjoined figure represents a side elevation of the double wooden railway: *a a* are the rails fastened down upon the cross sleepers *b b b*, similar to those of the single-way, which it also represents; *c c* the

upper rails laid upon the other, and firmly secured to them by wooden pins, in the same manner as the other are fastened to the sleepers. In the single-way, the joinings of the rails are necessarily upon a sleeper, as shewn at *d*; but in the double-way it is not so, for, being fastened down upon the surface of the under rail, which presents a continuous bearing, they can be secured anywhere along it; *e e* shew the joinings of the upper rail, midway between the cross sleepers, but they may be varied according to the upper lengths of timber. This prevents the under rail from being destroyed by the frequent perforation of the pin-holes in receiving the upper or wearing rails, and saves the waste of timber occasioned by the use of the single-way.



The sleepers, or transverse bearers, in this description of road, were generally formed of young saplings, or strong branches of the oak, obtained by thinning the plantations, and were six feet long, containing a sectional area of about thirty inches. At their first introduction, the under rail was of oak, and afterwards of fir, mostly in six feet lengths, and about five inches square, reaching across three sleepers, each two feet apart. The upper rail was of the same dimensions, and generally made of beech or planetree. The surface of the ground being formed pretty even about two yards in width, for the whole length of the intended "waggon-way," the sleepers were then laid down two feet apart, and the under rail properly secured to them. The ashes, or material forming the surface of the ground, were then beat firmly against the under

surface of the rails, which were thus strengthened and made more rigid. The upper rail was then placed upon the lower one, and firmly bound down by wooden pins.

This combination had many advantages over the single rail; for, independent of the waste of timber before alluded to, the destruction of the cross-sleepers in the single rail by the feet of the draught horses was considerable. The double rail, by increasing the height of the surface whereon the carriages travelled, allowed the inside of the road to be filled up with ballast to the top of the under rail;—thus, there were about six inches in depth of ballast upon the cross sleepers, which secured them against the propulsion of the horses' feet. This description of road continued in use for a considerable period of time, in various parts of the island, but especially amongst the collieries of Durham and Northumberland.

The next improvement in railroads says Mr. Hebert, was the adoption of iron for wood, which alone enabled the horse to take double his previous load. This change was not first introduced at Newcastle, as is generally supposed, but at the iron-works of Colebrook-dale, in Shropshire, about the year 1767. Our authority for this statement, continues Mr. H., is derived from the reports of a committee of the House of Commons, on the subject of roads and carriages. It occurs incidentally in a letter to the committee, from the ingenious Hornblower, the rival and contemporary of the celebrated Watt, who observes—"railways have been in use in this kingdom, time out of mind, and they were usually formed of scantlings of good sound oak, laid on sills or sleepers of the same timber, and pinned together with the same stuff:

but the proprietors of Colebrook-dale Iron Works, a very respectable and opulent company, eventually determined to cover these oak rails with cast-iron, *not altogether as a necessary expedient of improvement, but in part as a well-digested measure of economy, in support of their trade.* From some adventitious circumstances, which I need not take time to relate, the price of pigs became very low, and their works being of great extent, in order to keep the furnaces on, they thought it would be the best means of stocking their pigs, to lay them on the wooden railways, as it would help to pay the interest by reducing the repairs of the rails; and, if iron should take any sudden rise, there was nothing to do but to take them up, and send them away as pigs.

But these scantlings of iron, as I may call them, were not such as those which are now laid in some places; they were about five feet long, four inches broad, and one inch and a quarter thick, with three holes, by which they were fastened to the rails, and very complete it was, both in design and execution."* But, antecedent to the above date (1716), malleable-iron was used in the north. It was fastened upon the timber lines by plate-rails, in order to reduce the friction thereon; and was much used where the roads were of great curvature.

Tram Roads.—About the year 1776, cast iron plates having an upright ledge, were invented by Mr Curr, and introduced into the mines of the Duke of Norfolk, near Sheffield. They were at first called plate-rails, but are now usually termed tram-plates, owing to their being used for trams to run upon.

* "*Engineers' and Mechanics' Encyclopædia,*" art.—Railways; where will be found, ample information relative to the recent improvements which have been effected in railroads, and the carriages employed thereon.

Edge-Rails.—The precise time, or by whom those rails were first introduced, does not distinctly appear. But in the year 1789, Mr Jessop formed the public railroad at Loughborough, in Leicestershire, with cast iron edge-rails; the upper surface of which was elliptical. The wheels of the carriages being provided with proper flanges to guide them, when rolling along the tracks of the road.

Stone Blocks for supporting the iron rails, were originally introduced by Mr Barnes, in the year 1797, when forming the railway from Walker colliery, to the river, near Newcastle-upon-Tyne. The stone was procured at Lawson Main Quarry.

About the year 1805, malleable iron rails were tried at Walbottle Colliery, near Newcastle-upon-Tyne; the rails were square bars, two feet in length, joined together by a half-lap joint, with one pin; one end of the rail projecting beyond the end of the adjoining one, two or three inches. Their use was not at that time extended; their upper surface being too narrow, cut the periphery of the wheels, and they were superseded by cast iron rails of greater breadth.

According to the statement of Lord Carlisle's agent, Mr Thompson, malleable iron rails were used at his lordship's coal-works, on Tindale Fell, Cumberland, in the year 1808; and it appears from him, that they had given general satisfaction. For after having been "laid down for sixteen years, there was no appearance of lamination," and that "the rails then appeared very little worse."

Malleable Iron Edge Rails.—Previous to the year 1820, Malleable Iron was only used in bars of from two to three feet in length, either flat or in bars, from one to two inches square. They were productive of much injury to the periphery

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of the wheels, owing to their narrow surface, and if made of greater breadth, and sufficient strength for the carriages to roll along with safety, their expense became much greater than those of cast iron, which made the latter preferred. To remedy these defects, and reduce the number of joinings, &c., Mr. Birkenshaw, of the Bedlington Iron Works, obtained a patent in October, 1820, for making malleable iron edge rails, in lengths of about eighteen feet each, similar in shape to the cast iron ones then used. They were then made, as at present, by passing the bars, when hot, through rollers having indentations or grooves in their peripheries, corresponding with the intended shape of the rails.

RAILWAYS.—It would appear that the first public railway company was instituted at Loughborough, in the year 1789, for the purpose of making a railway a few miles in length; but the first public railway company that prosecuted their works to any extent, was that enterprising body the Society of Friends, who successfully completed that stupendous undertaking the Stockton and Darlington railway—then unrivalled—and which first stimulated British genius to contemplate the forming such gigantic works as have, since that time, been triumphantly effected, despite of all interested, and for a length of time, preponderant opposition.

The length of the Stockton and Darlington railway, including its branches, is fifty miles; and there has been a capital of about four hundred and fifty thousand pounds expended in its formation. The utility of this road may be attested by the fact that upwards of half a million tons of coal passed along the line last year; about four-fifths of which were exported, the remainder being disposed of at the numerous depôts along the line. The superi-

ority of locomotive railway travelling, and the increase of passengers resulting therefrom is fully exemplified upon this road, where the intercourse of passengers is now augmented to upwards of eighty times the extent to which it was carried on prior to the formation of the railway, notwithstanding the facilities hitherto afforded by the excellent blue whinstone turnpike roads, running in an almost parallel direction. The principal works upon the railroad are the suspension and draw bridges, near Stockton, across the river Tees; the stone bridge across the river Skerne, near Darlington; the shipping apparatus at Middlesbro,' in Yorkshire; and the great stationary engine on Brusselton Hill, which draws the coals, &c., from the Auckland valley to the summit of the railroad, in order that they may be forwarded to the western terminus of the great eastern locomotive plane at Shildon.

About two miles below the terminus last adverted to, commences the Clarence Railway, and which proceeds in an eastern direction terminating at Port Clarence, on the northern bank of the river Tees, nearly opposite to the town of Middlesbro'. Upon this line, there is one plane nine miles in length, possessing the favourable declination for the descending trade of 23.36 feet per mile, which, considering the very undulating surface of its route, reflects great credit on its designer, it being considered, when made, a close approximation to the equalised plane. Rather less inclination was deemed preferable at the time alluded to, but it could not be obtained, owing to the descent of the country, and the non-intervention of any plane between the termini, except those for locomotive power. The trade upon this railway has

recently been considerably increased, two hundred thousand tons of coals having passed along it during the year 1838; and the railway company have lately had guaranteed to them an annual quantity of one hundred and fifty thousand tons, to be led from the great western coal field now being opened out, and which quantity, in all probability, will very soon be doubled; therefore, it appears that ere long, this line of communication will be more fully developed than it has been hitherto. There have been some extensive works executed upon this railroad. The first that we shall notice is the great river embankment and the several drops at Port Clarence; the shipping apparatus, for alternately lowering the loaded coal waggons to the ship's deck, and lifting them up again when emptied—the drops being justly admired for their simple construction, and expeditely loading vessels at all times of the tide. About five miles west of the above town commences the great Russell's cut, which contained four hundred thousand cubic yards of earth, the greatest depth being thirty feet. Three miles to the westward commences the Whitton cut, which contained two hundred and twenty thousand cubic yards, the middle portion averaging forty-two feet in depth. Adjoining, is the great Whitton embankment of seventy-five feet in height; and three miles further west is the Stillington embankment, sixty feet in height. On the north branch line, six miles from the city of Durham, is the Rudds Hill excavation; the railway is here cut through the solid rock to a depth of sixty-seven feet; the breadth at top is seventy-five feet, and one third of that breadth at the formation level. There were nearly one hundred thousand cubic yards of stone removed from this excavation.

STANHOPE AND TYNE RAILWAY.—Another opulent and persevering company have carried a railway from the river Tyne, at South Shields, in a north-west direction, forming an outlet to several collieries in its route, and also affording great facilities to the celebrated lime-works in the western part of this county—Durham. In consequence of the undulating surface, the western part of the line is worked on the self-acting inclined plane, and stationary engine principle. At Shields, there is an extensive quay completed, upon which are erected stone piers, to carry the several drops and the timber roadway, the trussed framing supporting the latter being a highly creditable specimen of constructive carpentry.

Upon the Hartlepool railway several extensive works have been completed. There were excavated from the great Crimdon cut, upwards of eight hundred thousand cubic yards of earth; its greatest depth is seventy feet; greatest width at the top, eighty yards, and nine yards in width at the formation level; the greatest part of it was deposited in the stupendous Hartlepool embankment, and the remainder of the latter formed with the earth excavated from the docks at Hartlepool. The residue of the above great cut was deposited in the adjoining Hesleton-dene embankment, of eighty-five feet in height, and the deficiency to form it obtained from the adjacent north-west cuttings. The Edderacres embankment, near Castle Eden, is seventy feet in height, and that at Pespool sixty feet. In consequence of the formation of this railroad, the small fishing town of Hartlepool has rapidly risen into importance, as a port of traffic and refuge.

We cannot close this retrospective view of the foregoing railroads already executed in the north, without a glance, however cursory, at that noble work of art, the Liverpool and Manchester railway, which clearly evinced the utility of such speculations, and accelerated the formation of the London and Birmingham, Grand Junction, Great Western, and other gigantic railroads, which are now of such national importance.

The distance between Liverpool and Manchester by the railroad is thirty-one miles. The great tunnel at the former place is one and a quarter miles in length, twenty-two feet wide, and sixteen feet in height; the side walls being five feet high, surmounted by a semicircular arch of eleven feet radius. Olive Mount excavation, near Liverpool, is seventy feet in depth, and two miles in length. The next object worthy of notice, is Parr Moss, where twenty-five feet of embankment have been required to form one of five feet high, owing to the imperfect foundation. The Sankey viaduct, nearly fourteen miles from Liverpool, contains nine arches, of fifty feet span each, the railroad upon it being elevated seventy feet above the valley; the structure is principally brick, having stone facings. We next arrive at the large Kenyon excavation, from which there were eight hundred thousand cube yards of earth removed. After passing three or four bridges, we enter the Chatt Moss level. This morass varies in depth from ten to forty feet, and comprises an area of nearly eight thousand acres. On the eastern border it was with much difficulty that the embankment could be consolidated, but time, ingenuity, and perseverance finally became predominant. Throughout the line of rail-

road, there were excavated and removed, upwards of three millions of cubic yards of stone, clay, and other soils.

CHAPTER III.

GRADIENTS.

Of expressing the Rate of Inclinations—Rules for calculating the several parts of Inclined Planes—Estimated by Geometry—Tables of Gradients—Rule for ascertaining the proper Inclination, to equalise the Draught in each direction, for a Descending Trade—Examples shewing how to calculate by it—Ratio of Waggons of one-third, fourth, and fifth parts of the weights of the gross downward Load, explanatory of the Equalised Planes.

Without wishing to appear fastidious, it may be necessary to observe, that, when speaking of gradients, they are sometimes expressed as at a rate of one yard perpendicular to so many yards horizontal, or at a rate of one foot perpendicular to so many feet horizontal. But such extra explanations are quite superfluous, as it is generally understood when we say 1 in 100, 1 in 200, and so on, that the first number represents the perpendicular height, and the latter the horizontal length in attaining such height, and that both numbers are of the same denomination, as yards, feet, &c., unless expressly *stated otherwise*. We shall, therefore, throughout this work, omit specifying whether the inclinations are in feet, or any other measure.

It may be necessary to observe that the inclination of a plane; the sine of inclination; the height per mile, or the height for any length; and the ratio, &c., are all understood as synonymes.

Having the inclination, per foot, of a plane given to find the corresponding inclination per mile, chain, or yard; also to find the ratio of the plane.

1.—Multiply the inclination per foot by 5280, (the number of feet contained in a mile) and the product will be the inclination per mile.

2.—Inclin. per ft.×66=inclin. per chain.

3.—Inclin. per ft.×3=inclin. per yard.

4.—Divide 12 by the inclin. per foot, and the quotient will represent the ratio of the plane. If calculated decimally, annex *as many* cyphers to the 12 for a dividend as there are decimals contained in the divisor.

EXAMPLES.

1.—A plane ascending at the rate of $\frac{1}{16}$ in. per foot:
then $\frac{1}{16}\times\frac{5280}{1}=\frac{5280}{16}=330$ in. or $27\frac{1}{2}$ ft. per ml.
By decimals—$\frac{1}{16}$ of an in.=·0625;
then ·0625×5280=330· in., or 27·5 ft. per mile.

4.—Plane ascending $\frac{3}{16}$ of an inch per foot:*
then $\frac{12}{1}\times\frac{16}{3}=\frac{192}{3}=64$, ratio of the plane, 1 in 64.
By decimals,
then 12·0000÷·1875=64, ratio of the plane 1 in 64.

The ascent, per yard, being given, to find the same ascent, per mile, per chain, or per foot; also, to find the ratio of the plane.

1.—Ascent per yard×1760=ascent per mile.

2.—Ascent per yard×22=ascent per chain.

3.—Ascent per yard÷3=ascent per foot.

4.—Divide 36 (the number of inches contained in a yard) by the ascent per yard, and the quotient will be the ratio of the plane. If calculated decimally, annex cyphers as before.

* The above 3-16ths of an inch, and the subsequent divisors, are inverted in order to divide fractionally.

EXAMPLES.

1.—Plane ascending $\frac{3}{16}$ of an in. per yard:
$\frac{3}{16}\times\frac{1760}{1}=\frac{5280}{16}=330$ in. or $27\frac{1}{2}$ ft. per ml.

By decimals,
$\cdot1875\times1760=330\cdot$ in., or $27\cdot5$ ft. per ml.

4.—A plain ascending $\frac{3}{16}$ of an inch per yard,
$\frac{36}{1}\times\frac{16}{3}=\frac{576}{3}=192$, 1 in 192, ratio of the plane.

By decimals,
$36\cdot0000\div\cdot1875=192$, 1 in 192, ratio of the plane.

The inclination, per chain, being given to find the same inclination per mile, yard, or per foot; also to find the ratio of the plane.

1.—Inclin. per chain$\times80=$inclin. per mile.

2.—Inclin. per chain$\div22=$inclin. per yard.

3.—Inclin. per chain$\div66=$inclin. per foot.

4.—Divide 792 (the number of inches contained in a chain) by the inclination per chain, and the quotient will be the ratio of the plane. If calculated by decimals, annex *as many* cyphers to the 792 for a dividend as there are decimals contained in the divisor.

EXAMPLES.

1.—Ascent of plane $4\frac{1}{8}$ in. per chain,
$4\frac{1}{8}$ in.$=\frac{33}{8}\times\frac{80}{1}=\frac{2640}{8}=330$ in., or 27 ft. 6 in. per mile.

By decimals,
$4\cdot125\times80=330\cdot$ in., or $27\cdot5$ ft. per ml.

2.—Inclin. of plane $4\frac{1}{8}$ in. per chain,
$4\frac{1}{8}$ in.$=\frac{33}{8}\times\frac{1}{22}=\frac{33}{176}=\frac{3}{16}$ of an in. per yd.

4.—Ascent of plane $4\frac{1}{8}$ in. per chain$=\frac{33}{8}$,
$\frac{792}{1}\times\frac{8}{33}=\frac{6336}{33}=192$, 1 in 192, ratio of the plane.

Decimally,
$792\cdot000\div4\cdot125=192$, 1 in 192, as above.

The inclination, per mile, being given to find the the same inclination per chain, yard, or per foot; or to find the ratio of the plane.

1.—Inclin. per mile$\div$80=inclin. per chain.

2.—Inclin. per mile$\div$1760=inclin. per yard.

3.—Inclin. per mile$\div$5280=inclin. per foot.

4.—Divide 5280 (the number of feet=1 mile) by the inclination per mile;—if the latter contain feet and inches, reduce it to inches, and divide 63,360 (the number of inches=1 mile) by the inches in the inclination given, and the quotient, in either case, will represent the ratio of the plane.

EXAMPLES.

1.—Ascent of plane $27\frac{1}{2}$ feet per mile=330 inches, $\frac{330}{1}\times\frac{1}{80}=\frac{330}{80}=4\frac{1}{8}$ inches per chain.

2.—Same plane,
330$\cdot\div$1760=$\cdot$1875 inches per yard.

4.—Plane ascending 24 feet per mile,
5280$\div$24=220, ratio of the plane, 1 in 220.
Plane ascending $27\frac{1}{2}$ feet per mile,
63,360$\div$330=192, ratio of the plane, 1 in 192.

Having the ratio of a plane given, to find its inclination per mile; chain; yard; foot; or for any length of it.

1.—$\frac{\text{5280 feet}}{\text{ratio}}$=inclin. per mile in feet; or

$\frac{\text{63,360 inches}}{\text{ratio}}$=inclin. per mile in inches.

2.—$\frac{\text{792 inches}}{\text{ratio}}$=inclin. per chain in inches.

3.—$\frac{\text{36 inches}}{\text{ratio}}$=inclin. per yard in inches.

4.—$\frac{\text{12 inches}}{\text{ratio}}$=inclin. per foot in inches.

5.—$\frac{\text{Length of Plane, in feet}}{\text{ratio}}$=inclin. of any length of the plane in feet.

EXAMPLES.

1.—Plane ascending at the rate of 1 in 192,
$5280 \div 192 = 27 \cdot 5$ feet per mile; or
$63{,}360 \div 192 = 330$ inches per mile.

2.—Plane ascending at the rate of 1 in 1056,
$\frac{792}{1} \times \frac{1}{1056} = \frac{792}{1056} = \frac{3}{4}$ths of an inch per chain.

3.—Ascent of plane 1 in 192,
$\frac{36}{1} \times \frac{1}{192} = \frac{36}{192} = \frac{3}{16}$ths of an inch per yard.

5.—A plane, 880 yards in length, ascending at the rate of 1 in 192, 880 yards=2640 feet,
$2640 \div 192 = 13 \cdot 75$ feet=the inclin. of the plane.

MISCELLANEOUS EXAMPLES.

Plane, 2640 yards in length, ascending at the rate of 27 feet 6 inches per mile,
$1760 : 2640 :: 27\frac{1}{2} : 41\frac{1}{4}$ feet=the height of the plane; or
$5280 : 7920 :: 330 : 495$ in.=the height of the pl.

Plane, 2640 yards in length, ascends 41 feet 3 inches, what is the inclin. per mile; chain; and per yard?
$2640 : 1760 :: 41\frac{1}{4} : 27\frac{1}{2}$ feet.=the height per mile; or
$7920 : 5280 :: 330 : 495$ in.=the height per ml.
$2640 : 22 :: 495 : 4\frac{1}{8}$ in.=the height per chain.
$2640 : 1 :: 495 : \cdot 1875$ in.=the height per yd.

What is the ratio of the above plane; or what length of it=1 yard,
$495 : 36 :: 2640 : 192$ yds.=1 yd., or the ratio of the plane is 1 in 192 yds.

Gradients are also calculated geometrically, thus:—the hypothenuse^2 of any right-angled triangle=the base^2+height^2; and the base^2=hypothenuse^2—height^2; and the height^2=hypothenuse^2—base.^{2} The hypothenuse being understood as the length of the plane. But, in general, gradients are easiest calculated decimally; as shewn in some of the preceding examples.

In all such questions as the last, in simple proportion, there will always be three terms, one of which is of the same kind as the answer sought; and the simplest, and surest, way to operate is, to put that term in the third place. It will then readily be seen, whether the answer is required greater or less than that sum, therefore, place the other two terms first and second, according as it is required, less or more; such two terms being always of the same kind, as, inches, feet, &c. Thus, in the example adverted to, the answer was, how many *yards*=1 yard? The length, 2640 yards, was, therefore, put in the third place. Now, as 2640 yards ascends 495 inches, it was evident that a shorter length would ascend 1 yard. Consequently, the 495 was placed for the first, and the 1 yard (36 inches) for the second term. It is to be observed, that the product of the two means, and that of the two extremes, must always be equal. Thus, in this example, $36 \times 2640 = 95,040$ =the two means; and $495 \times 192 = 95,040$=the two extremes.

In stating the ratio of each plane, in the last columns of the subjoined tables, the fractional parts have been omitted, and the nearest integral number inserted;—the table being intended as a reference for practical purposes, such minutiæ, would have appeared superfluous. The planes marked with an * in the first table, are the nearest corresponding heights, per mile, to the equal ratios of plane, inserted in the last columns.

TABLE OF PLANES,

Showing the rate of ascent per mile, and the corresponding ascent per chain, per yard; and also the ratio.

ASCENT OF PLANE.					ASCENT OF PLANE.				
Per Mile.		PerChn.	Per Yard.	Ratio.	Per Mile.		PerChn.	Per Yard.	Ratio.
Ft.	In.	Inches.	Inches.	One in	Ft.	In.	Inches.	Inches.	One in
1	0	·15	·0068	5280	9	4	1·40	·0636	566
1	4	·20	·0091	3960	9	7*	1·44	·0653	550
1	8	·25	·0114	3168	9	8	1·45	·0659	546
2	0	·30	·0136	2640	10	0	1·50	·0682	528
2	4	·35	·0159	2263	10	4	1·55	·0705	511
2	8	·40	·0182	1980	10	7*	1·59	·0722	500
3	0	·45	·0205	1760	10	8	1·60	·0727	495
3	4	·50	·0227	1584	11	0	1·65	·0750	480
3	8	·55	·0250	1440	11	4	1·70	·0773	466
4	0	·60	·0273	1320	11	8	1·75	·0795	453
4	4	·65	·0295	1218	11	9*	1·76	·0801	450
4	8	·70	·0318	1131	12	0	1·80	·0818	440
5	0	·75	·0341	1056	12	4	1·85	·0841	428
5	3*	·79	·0358	1000	12	8	1·90	·0864	417
5	4	·80	·0364	990	13	0	1·95	·0886	406
5	7*	·84	·0381	950	13	2*	1·97	·0898	400
5	8	·85	·0386	932	13	4	2·	·0909	396
5	10	·87	·0398	900	13	8	2·05	·0932	386
6	0	·90	·0409	880	14	0	2·10	·0955	377
6	3*	·94	·0426	850	14	4	2·15	·0977	368
6	4	·95	·0432	834	14	8	2·20	·1	360
6	7*	·99	·0450	800	15	0	2·25	·1023	352
6	8	1·	·0455	792	15	4	2·30	·1045	344
7	0	1·05	·0477	754	15	8	2·35	·1068	337
7	1*	1·06	·0482	750	16	0	2·40	·1091	330
7	4	1·10	·05	720	16	4	2·45	·1114	323
7	7*	1·14	·0518	700	16	8	2·50	·1136	317
7	8	1·15	·0523	689	17	0	2·55	·1159	311
8	0	1·20	·0545	660	17	4	2·60	·1182	305
8	4	1·25	·0568	634	17	7*	2·64	·1199	300
8	8	1·30	·0591	609	17	8	2·65	·1205	299
8	10*	1·32	·0603	600	18	0	2·70	·1227	293
9	0	1·35	·0614	587	18	4	2·75	·1250	288

ASCENT OF PLANE.					ASCENT OF PLANE.				
Per Mile.		PerChn.	Per Yard.	Ratio.	Per Mile.		Per Chain	Per Yard.	Ratio.
Ft.	In.	Inches.	Inches.	One in	Ft.	In.	Inches.	Inches.	One in
18	8	2·80	·1273	283	45	0	6·75	·3068	117
19	0	2·85	·1295	278	46	8	7·	·3182	113
19	4	2·90	·1318	273	48	4	7·25	·3295	109
19	8	2·95	·1341	268	50	0	7·50	·3409	106
20	0	3·	·1364	264	51	8	7·75	·3523	102
20	4	3·05	·1386	260	52	10*	7·93	·3602	100
20	8	3·10	·1409	255	53	4	8·	·3636	99
21	0	3·15	·1432	251	55	0	8·25	·3750	96
21	4	3·20	·1455	247	56	8	8·5	·3864	93
21	8	3·25	·1477	244	58	4	8·75	·3977	91
22	0	3·30	·15	240	58	8	8·80	·4	90
22	4	3·35	·1523	236	60	0	9·	·4091	88
22	8	3·40	·1545	233	61	8	9·25	·4205	86
23	0	3·45	·1568	230	63	4	9·50	·4318	83
23	4	3·50	·1591	226	65	0	9·75	·4432	81
23	8	3·55	·1614	223	66	8	10·	·4545	79
24	0	3·60	·1636	220	68	4	10·25	·4659	77
24	4	3·65	·1659	217	70	0	10·50	·4773	75
24	8	3·70	·1682	214	71	8	10·75	·4886	74
25	0	3·75	·1705	211	73	4	11·	·5	72
25	4	3·80	·1727	208	75	0	11·25	·5114	70
25	8	3·85	·1750	206	76	8	11·50	·5227	69
26	0	3·90	·1773	203	78	4	11·75	·5341	67
26	4	3·95	·1795	200	80	0	12·	·5455	66
26	8	4·	·1818	198	81	8	12·25	·5568	65
28	4	4·25	·1932	186	83	4	12·50	·5682	63
29	4	4·40	·2	180	85	0	12·75	·5795	62
30	0	4·50	·2045	176	86	8	13·	·5909	61
31	8	4·75	·2159	167	88	0	13·20	·6	60
33	4	5·	·2273	158	88	4	13·25	·6023	60
35	0*	5·25	·2386	150	90	0	13·50	·6136	59
36	8	5·50	·2500	144	91	8	13·75	·6250	58
38	4	5·75	·2614	138	93	4	14·	·6364	57
40	0	6·	·2727	132	95	0	14·25	·6477	56
41	8	6·25	·2841	127	96	8	14·50	·6591	55
43	4	6·50	·2955	122	98	4	14·75	·6705	54
44	0	6·60	·3	120	100	0	15·	·6818	53

TABLE OF PLANES,

Shewing the Ascent per Yard, and the corresponding Ascent per Chain per Mile and also the Ratio.

ASCENT OF PLANE.				
Per Yard.		Per Chain.	Per Mile.	Ratio.
In pts. of an inch.	In decls. of an inch.	Inches.	Feet.	One in
$\frac{1}{64}$	·0156	·344	2·29	2304
$\frac{1}{48}$	·0208	·458	3·06	1728
$\frac{1}{32}$	·0312	·687	4·58	1152
$\frac{1}{24}$	·0417	·917	6·11	864
$\frac{1}{16}$	·0625	1·375	9·17	576
$\frac{1}{12}$	·0833	1·833	12·22	432
$\frac{1}{10}$	·1	2·2	14·67	360
$\frac{1}{8}$	·125	2·75	18·33	288
$\frac{1}{6}$	·1667	3·667	24·44	216
$\frac{3}{16}$	·1875	4·125	27·50	192
$\frac{1}{5}$	·2	4·4	29·33	180
$\frac{1}{4}$	·25	5·5	36·67	144
$\frac{3}{10}$	·3	6·6	44·	120
$\frac{5}{16}$	·3125	6·875	45·83	115
$\frac{1}{3}$	·3333	7·333	48·89	108
$\frac{3}{8}$	·375	8·25	55·	96
$\frac{2}{5}$	·4	8·8	58·67	90
$\frac{5}{12}$	·4167	9·167	61·11	86
$\frac{7}{16}$	·4375	9·625	64·17	82
$\frac{1}{2}$	·5	11·	73·33	72
$\frac{9}{16}$	·5625	12·375	82·5	64
$\frac{7}{12}$	·5833	12·833	85·56	62
$\frac{3}{5}$	·6	13·2	88·	60
$\frac{5}{8}$	·625	13·75	91·67	58
$\frac{2}{3}$	·6667	14·667	97·78	54
$\frac{11}{16}$	·6875	15·125	100·83	52
$\frac{7}{10}$	·7	15·4	102·67	51
$\frac{3}{4}$	·75	16·5	110·	48
$\frac{4}{5}$	·8	17·6	117·33	45
$\frac{13}{16}$	·8125	17·875	119·17	44
$\frac{5}{6}$	·8333	18·333	122·22	43
$\frac{7}{8}$	·875	19·25	128·33	41
$\frac{9}{10}$	·9	19·8	132·	40
$\frac{11}{12}$	·9167	20·167	134·44	39
$\frac{15}{16}$	·9375	20·625	137·5	38
$\frac{1}{1}$	1·	22·	146·67	36

Descending Planes—It may be necessary to remark that all lines are considered as descending ones, where there is a constant greater weight drawn in one direction than in the opposite one.

The following rule evinces the method of calculating the proper inclination for gradients of the above description. "To the tonnage in each direction add the weight of the waggons required to carry the greater tonnage, divide the greater sum by the less, and make the quotient, diminished by 1, the numerator, and the same quotient, with 1 added, the denominator of a fraction. Multiply this fraction by the fraction representing the resistance on the level rails, and the result will be the fraction shewing the best inclination for the trade."
—*Tredgold.*

EXAMPLES.

1.—Suppose that for every 1000 tons of goods conveyed in one direction, there will be only 500 tons drawn in the opposite one; and that the weight of the waggons to carry 1000 tons is 250 tons, (one-fifth of the gross downward trade). First, add to 1000 tons the weight of the waggons, which makes 1250 tons; and to the 500 tons, their weight added will make 750 tons. Then divide 1250 by 750; that is $\frac{1250}{750}=1{\cdot}667$. Then from 1·667 subtract 1 for a numerator, and add 1 for a denominator, and we have $\frac{\cdot 667}{2\cdot 667}=\frac{1}{4}$. Now if 1 lb. will draw 150 lbs. upon the level railroad, then $\frac{1}{4}\times\frac{1}{150}=\frac{1}{600}$, or the plane should descend 1 in 600, to equalise the tractive power thereon.

2.—Again, suppose 1 lb. would draw 240 lbs. upon the level then $\frac{1}{4}\times\frac{1}{240}=\frac{1}{960}$, or the plane should descend 1 in 960, to equal the tractive power.

3.—If the empty waggons only were to be returned, and their weight, and the resistance on the level, as in example the first;

then, $\frac{1250}{250}=5$, and $\frac{5-1}{5+1}=\frac{1}{1.5}$; hence,

$\frac{1}{1.5}\times\frac{1}{150}=\frac{1}{225}$, or a plane descending 1 in 225, would balance the draught.

4.—If the empty waggons only were to be returned, and their weight, as in example the first, the resistance on the level=240th part as before;

then, $\frac{1}{1.5}\times\frac{1}{240}=\frac{1}{360}$, or the plane should descend 1 in 360, to equalise the draught.

5.—Suppose the empty waggons only were to be returned, and their weight was equal to one-fourth of the gross load, (one-third of the useful effect,) and the resistance on the level equal to the 150th part of that weight.

1,000 tons goods+333, wt. of wgs.=1,333 tons gross.

then, $\frac{1333}{333}=4$, and $\frac{4-1}{4+1}=\frac{1}{1.67}$;

hence, $\frac{1}{1.67}\times\frac{1}{150}=\frac{1}{250}$, or a plane descending 1 in 250 would obtain the same result, as 1 in 360 does in the last example.

6.—Suppose the empty waggons only were to be returned, and that their weight equalled one-third of the gross load ($\frac{1}{2}$ the useful effect).

1000 tons goods+500, wt. of wgs.=1500 tons gross.

then, $\frac{1500}{500}=3$, and $\frac{3-1}{3+1}=\frac{1}{2}$, or the descent should be equal to $\frac{1}{2}$ the resistance upon the level.

According to the weights, &c., given in the first example, it appears that the proper inclination should be one-fourth of the resistance upon the level railroad; in the second equal to $\frac{1}{1.5}$th, and so on, to equalise the draught in each direction. It will also be observed that the equalised draught alters the proper declivity according to the ratio of weight that the waggons bear to the gross load. The lighter they are, of course the greater acclivity is requisite to balance the preponderating downward trade.

We shall now proceed to show that the preceding inclinations of plane are correctly balanced.

1.—Supposing a power of 100 lbs. be applied upon a railway where the resistance upon the level equals the 150th part of the insistent weight, what weight will it draw down a plane of 1 in 600?

$100 \times 150 = 15{,}000$ lbs., drawn on the level;
then, $15{,}000 \div 150 = 100$ lbs., friction on the level;
$15{,}000 \div 600 = \underline{\ 25}$, gravity of plane;
75 lbs., total resistance.

and $\frac{100 \times 15{,}000}{75} = 20{,}000$ lbs. = the weight drawn down the plane.

2.—The resistance upon the level being the same, what weight would the 100 lbs. power draw up the same plane?

Here the resistance upon the level must be added to the gravity of the plane. Friction on the level, 100 lbs. + gravity, $25 = 125$ lbs., total resistance. And $125 : 100 :: 15{,}000 : 12{,}000$ lbs., = the weight drawn up the plane. And the 20,000 lbs. drawn down in the last example : this 12,000 lbs. :: 1,250 tons : 750 tons, returned in the first example in page 49. Consequently, it proves that a plane descending 1 in 600, $(\frac{1}{4} \times \frac{1}{150})$ equalises the draught, where the weights drawn in each direction, and that of the waggons is as there described.

3.—If a power of 100 lbs. were applied on a railway, where the resistance on the level equalled the 150th part of the insistent weight, what weight would it draw down a plane of 1 in 250?

$100 \times 150 = 15{,}000$ lbs., drawn on the level;
then, $15{,}000 \div 150 = 100$ lbs., friction on the level;
$15{,}000 \div 250 = \underline{\ 60}$, gravity:
40 lbs., total resistance.

and, $\frac{100 \times 15{,}000}{40} = 37{,}500$ lbs. = the weight drawn down the plane.

4.—What weight would the 100 lbs. power draw up the plane of 1 in 250, the resistance on the level being the same as in the last example?

Here, the friction upon the level must be added to the gravity of the plane. Friction on the level, 100 lbs.+gravity, 60=160 lbs. total resistance. And, 160 : 100 : : 15,000 : 9,375 lbs.=the weight drawn up the plane, and=$\frac{1}{4}$th of the descending load. It consequently follows that a plane descending 1 in 250 $\left(\frac{1}{1\cdot 67}\times\frac{1}{150}\right)$=the tractive power, where the load is only in one direction, and the weight of the waggons=one-fourth of the gross load. See example fifth, in the fiftieth page.

CHAPTER IV.

EXCAVATING.

Quantity of land required for a Railroad—Formation and Preservation of Slopes—Methods of staking out cuttings—Boring—System of Excavating—Cubic yards excavated per day by each individual—Expense of excavating per cubic yard—Employing Trams—Corves—Barrowing—" Horse-runs," or Vertical Roads—Gulleting—Its Advantages and Disadvantages—Excavating in Layers—Modes of working Descending Cuts—Excavating Rock—Great Blast of Rock, in Craigleith Quarry—American Patent for boring in Rock—Formation Level—Disruptions in Slopes—Drainage—Cowran Hills Cut, near Carlisle—Dwarf Walls—System of measuring Work, with Explanatory examples.

The quantity of land requisite for forming railroads, will depend upon various circumstances; such as, an undulating surface, breadth of tracks, depths of cutting, heights of embankments, &c. But, for a double line of railway, about twenty-seven yards may be assumed as a medial breadth, including fences; or about ten acres per mile, exclusive of that required at each terminus.

We shall consider the line of railway staked out, ready to commence operations. Should the ground not vary much transversely, or between the sides of the intended excavation, there will be little or no difficulty in setting out the work; on the contrary, if it presents a variable surface between its sides, the greatest precaution will be necessary, to preserve the uniformity of the slopes, and to keep

them as free as possible from indentations or asperities, which not only disfigure them, but tend to cause disruptions and slipping in their sides; the evil effects of which will be subsequently detailed. Moreover, an expense frequently incurred by re-working slopes, would also be avoided, by taking due precaution in setting them out before commencing to excavate. The angle of the slopes should also be attended to, being regulated by the nature of the material and the depth of the cutting; for the deeper the cut, the flatter ought they to be executed. And where the formation-level of the cut is soft, or where there is a deficiency of earth to form the embankments, it will be desirable to form the slopes very flat on the south side of the cuttings, to give greater facility to the action of the sun and wind, two powerful auxiliaries for constituting a firm foundation. It is also advisable to reserve the surface-soil to cover the slopes, that it may be afterwards sown with grass, which not only improves the appearance of the railroad, but also forms a good preventative against the destructive influence of the atmosphere; for, when the grass has once attained a proper sward, it acts as a shield, and being nearly impervious to wet, prevents the rain from washing the earth into the side drainage, or even penetrating the slopes. This is also a good method to adopt either with excavations or embankments, when composed of sand, in order to form on outer crust as a preventative against the powerful force of the wind, which frequently indents slopes to a great extent.

In setting out excavations where the surface slopes transversely, it is customary to mark them out as if level between their sides; then to take the difference of height between the low side and

centre of the railway, and deduct the difference—estimated according to the intended batter of slope—from the low side of the cut, and add it to the high one. This method answers for ordinary purposes, but not where the transverse slope is great.

When the transverse slope of the ground is considerable, as in cutting the side of a hill, the most correct method of excavating is to finish the slopes from the bottom of the cut upwards by a frame bevel, having something attached denoting its perpendicular, but if the work has to be permanently set out and fenced off, before commencing to excavate, this method, of course, cannot be resorted to; we would therefore suggest the making of a small sketch, or transverse section of the surface at different places, where the cut is of great depth, the surface irregular, or sloping much transversely. Each slope may then be marked off to similar or *different* angles, the width measured on the section, and the cut finally staked out.

It is essential to have the earth perforated at various places to the depth of the intended excavations, particularly where they are to be of great depth, in order to ascertain what the strata is composed of. Where cuttings are to be shallow this is easily effected, but where they are to be deep, recourse must be had to boring implements, such as are in general use.

The requisite cutting for forming embankments may in general be nearly ascertained, provided the ground be firm; but, when the substratum yields by the pressure of the mound, there are no data upon which to form a calculation. Although embankments are usually narrower than cuts, yet they may be supposed as equivalent to cuts of corresponding depth, on account of their slipping and waste before

being finally consolidated. Should there be a surplus of cutting, it will be desirable to reserve a portion of that part which is freest from clayey particles, for the purpose of repairing and raising the embankments as they subside.

Attempts have been made at different times to introduce machinery, for the purposes of excavating; but hitherto it has proved almost inoperative, owing chiefly to the difficulty of applying the machinery as the excavations become advanced. We, of course, do not allude to excavating in water, such as the deepening of rivers, where mechanical power is indispensable, and undoubtedly will maintain its predominance.

As earthworks have chiefly to be performed by manual labour, the main object to be accomplished when excavating, or what is termed "getting the earth," is to cause its specific gravity to assist in overcoming its tenacity. This is easily obtained by merely undermining it, where there is a good breadth of face, but where the breadth is limited, we prefer the cutting an upright chamber about two feet wide at each end, to nearly the breadth of the intended fall of earth; the material thus projecting, its gravity assists the operator in detaching it in considerable masses of many tons each, according to the nature of the strata. The extra trouble in cutting vertical niches, is far more than compensated by the trivial dressing requisite at the face, before another fall takes place. The working of some soils is yet further expedited, by placing a block a short distance from the face of the cut, the earth in falling acquires such a momentum that when it comes in collision with the block, it is comparatively ready for being loaded.

The quantity of earth cut and loaded in a

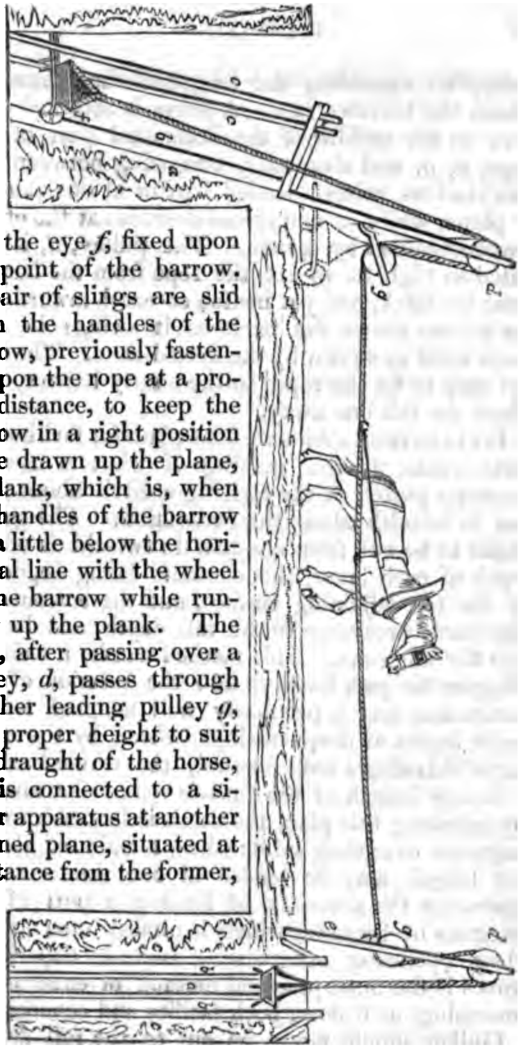
specified time, by each workman, is very fluctuating; the tenacity of the earth frequently making a difference of more than one hundred per cent.; exclusive of the variations of seasons. In many soils, we have known each man in the cut to excavate and load twelve cubic yards per diem; whereas, in others, each man scarcely averaged one-half that quantity for his day's work, even after the earth had been detached from the face of the cutting. Yet, upon the average, throughout a line of road in ordinary soils, (stone excepted,) we may fairly assume eight cubic yards of earth to be cut and loaded by each individual employed *in the cut* for his day's work; and taking them at an average of three shillings per day each, the expense of excavating and loading will amount to 4·5 pence per cubic yard.

In excavating, where the distance is short, barrowing is preferable to any other means, to the extent that manual power can be economically appropriated, on account of the simplicity of the machines, and the facility with which the stage is erected for their application. Indeed, we may truly say, that the quantity of earth removed in them per diem, by some workmen, is almost incredible; and their manner of running along a plank, across a deep chasm, where the height of the load often prevents their seeing the wheel of the barrow, is also astonishing. For greater distances, the best mode is in using small waggons, or corves placed upon trams; in either case running upon tramways, impelled by the workmen. When the nature of the soil is such that it is readily unloaded, these two latter methods are often preferable to the former, even for short lengths, but for the greater facility with which the barrows can be applied,

owing to a single plank in width sufficing for a road-way.

In the prosecution of earth-works, it frequently happens that the situations are so limited, that no road can be devised for the removal of the produce from a lower to a higher level, except those which are technically called "*horse-runs*;" that is to say, when the planks forming the road-ways are laid almost vertically, one man being drawn up along with a loaded barrow, whilst another man is being lowered down a similar plane with an empty one; or alternately drawn up and lowered down the same plane. The frequency of accidents upon such roads led to the following improvement. The engraving on the opposite page represents the plan alluded to, invented by Mr. Matthews, and which has been rewarded by the Society of Arts, by an honorary gold medal. By its adoption accidents are entirely avoided, as the barrows are alternately drawn up and lowered down without any workman accompanying them.

The plan, and method of operating is thus detailed by Mr. Hebert. *a a* is a plank ten or eleven inches wide, laid at a small angle, sufficient to keep the barrow wheel in contact with it, and two strips, *b b*, are spiked to the edge of the plank, so as to form a groove for the wheel to run in; two pieces of quartering, or small spars, *c c*, are fixed on each side, at a proper distance, to guide the handles, by which the barrow is kept in a proper position against the plank upon which the wheel runs; about ten or fifteen feet from the top of the plank, and the stage where the loaded barrow is to land, a pully, *d*, is fixed to a pole, *e*, through which the rope, or chain, is passed down to the barrow; to the end of the rope is fastened a hook, which goes



into the eye *f*, fixed upon the point of the barrow. A pair of slings are slid upon the handles of the barrow, previously fastened upon the rope at a proper distance, to keep the barrow in a right position to be drawn up the plane, or plank, which is, when the handles of the barrow are a little below the horizontal line with the wheel of the barrow while running up the plank. The rope, after passing over a pulley, *d*, passes through another leading pulley *g*, at a proper height to suit the draught of the horse, and is connected to a similar apparatus at another inclined plane, situated at a distance from the former,

somewhat exceeding the length of the planes on which the barrows run. A horse is attached by a rope to the middle of the horizontal part of the rope, *g*, *g*, and alternately traversing between the two stations, raises a loaded barrow at one station, or plane, whilst an empty one descends at the other, unaccompanied by a man. The pulley, *d*, is elevated so high as to let the rope from the barrow clear the bank, and yet incline so much inward that the barrow clears the bank as it swings in, and lands itself as shown by the dotted lines. The man has only to fix the ropes to the empty barrow, and wheel the full one away.

GULLETING.—An excellent plan for facilitating earth-works, is the making of what is usually termed a *gullet*, or the forming a ditch about nine feet in breadth along the excavation. The gullet ought to be cut from one-half to two-thirds of the depth of each layer, the contents being deposited on the top adjoining surface, and the bottom part afterwards excavated to the full depth, and loaded into the waggons. This method admits a train of waggons to pass forward into the interior of the excavation, and is peculiarly well adapted to the upper layers of deep cuttings, where, by the making of this single road forward, the whole breadth —for any length of the cut—is rendered available. By adopting this plan, the earth is loaded into the waggons over their sides; thus, a train of almost any length may be loaded at one time; it also supersedes the necessity of loading a part of the waggons by barrows, which is almost unavoidable when operating otherwise. Indeed, experience proves it the most practical method of excavating, possessing, as it does, both facility and economy.

Gullets should never be cut to the full depth,

before commencing to load the earth into the waggons. Casting out the bottom part of them is too expensive, moreover the produce has to be refilled; their sides are also more liable to be pressed in, owing to there being a greater weight resting upon them, and by their sides thus being deeper. There will generally be sufficient time to excavate the bottom part of the gullet, and load the produce into the waggons most advanced into the interior, without laying it down and refilling it, as the other waggons have to convey the whole depth of the layer, and also the excavated earth which has been deposited near the sides of the gullet.

When speaking of the advantages resulting from the introduction of gullets, it is necessary to remark that they are frequently prosecuted to too great an extent, especially during the winter months, or when the season is wet. Being made so much in advance of the finished layer, they are too long exposed to the weather, and by the action of the frost and wet, large quantities of the excavated earth and sides of the ditch are precipitated into the bottom, and which can only be removed at a great expense.

Gulleting is incompatible with shallow cuttings, unless that by excavating a road through an intervening space, it enables a cut of greater magnitude to be commenced. It is occasionally resorted to for expediting the work of the former, but which is nevertheless attended with additional expense; for the advantages resulting from the residue, after a gullet is made in shallow cutting, is not a compensation for its execution.

Excavating in Layers.—Where cuttings are deep, it is expedient to excavate in layers of from eight to twelve feet each, in order to diminish the

danger attendant upon those works as much as possible, and also to facilitate their progress; should there be a good deposit for the excavated earth, the work may then be prosecuted to almost any extent. Each layer ought to proceed with an uniform descent towards the place of delivery, on account of conveying the water from the face of the cut, and also to equalise the draught; which latter will be subsequently explained when treating on haulage. By operating in layers, the employing of barrows when loading the waggons, is also avoided; its adoption, however, causes an additional length of temporary roads requisite.

When excavations are performed to the required depth in two layers, both should be in operation at the same time, keeping the upper one any convenient distance advanced, and its produce conveyed to the lower layer by an inclined plane on one of the slopes. This method equalises the excavating; the higher layer being so much better adapted for excavating on account of its extra breadth. Where cuts are of great depth, the major part of the upper layers ought to be completed, as much of their contents as possible being conveyed down by means of self-acting inclined planes, before the lower layers are commenced.

DESCENDING CUTS.—In descending cuts, the water is frequently a formidable opponent to our proceedings; it is therefore desirable, that the greater part of the excavation should be executed on a level, or with a slight ascent, in order to lessen the inconvenience of quitting the water, and only have it to contend with when excavating the bottom part to the required depth. Should there be a great accumulation of water in the bottom, and it be difficult to quit, the best and most effectual

method is, to make an open drain from the lower end of the cutting, after the water level line is carried through.

We have occasionally observed cuts slightly descending, worked to the specified depth as they proceeded, merely by taking the precaution of keeping the face of the cut, and a short distance from it, a few inches above the proper depth, and bottoming the cut as it advanced, which kept the part in operation dry, and answered the purpose intended remarkably well.

Another mode of performing descending cuts where part of the produce is required for embanking at each end of the cut, is, to convey the upper part of the excavation into the ascending embankment, and afterwards bottom the excavation to form the lower one; this necessarily increases the average length of conveyance, yet the advantages consequent therefrom, will far more than compensate for the additional distance incurred.

Excavating Rock.—There is not such a discrepancy between the expense of cutting a line through a stony substance and ordinary soils as at first appears; owing to the angle of repose of rock being nearly vertical, which causes the cubical content to be considerably *less* than when passing through soils. The former certainly costs more for removing, than an equal mass of the latter; yet part of the product of the former is in many cases made available for useful purposes; its value frequently liquidating the expense incurred in removing the whole quantity. Rock has also an advantage over soils where there is a deficiency of embanking material, owing to its angle of rest being as above described, which renders a greater bulk attainable from the same width; the produce also

stands more erect when embanked; in both cases causing a less quantity of land to be requisite for the completion of a railway.

When there is a deficiency of embanking material, or when the product is valuable, rock excavations will probably be executed as wide as those composed of clay or other soils; in which case, perhaps, the best method of operating is by adopting gullets as in the sixtieth page; but in ordinary stone cuttings, this method will be inapplicable, on account of their limited width at the top, owing to their angle of repose being nearly perpendicular. It should also be observed, that, commonly, it will be the best to make the gullet adjoining one side of the cut, that one of the slopes may form a permanent side of the excavation when completed. But where the excavation is of a great width, it will be preferable to form the gullet along the middle of the cutting, which will render double the sectional area of face attainable for excavating.

In order to facilitate the progress of rock excavations of limited breadth, we would suggest that they should be formed in layers of about fifteen feet each, and the layers formed in two depths, which would allow of any space in the upper part being excavated at one time. Thus, each layer might be prosecuted at whatever rate was deemed necessary, merely by increasing the number of faces along its upper part, and depositing the contents upon the top of the lower one, to be removed as the lower part of the layer advanced. Although this method causes the produce of the upper part of each layer to be again removed, yet at the same time, it materially diminishes the danger attendant upon such works. It also causes a ready delivery when excavating the upper part, and also allows

the excavating to be accelerated without curtailing the space occupied by each workman. And, moreover, it enables the winning of each separate piece to be undertaken by a different sub-contractor, which is, in many cases, a great acquisition.

The following immense blast of rock took place in Craigleith quarry, near the city of Edinburgh, on Saturday, the 18th day of October, 1834. "At half-past two o'clock, the conductor, inclosed in a block-tin tube, twenty-six feet long and half-inch diameter, was introduced into the bore. The depth of the bore was sixty feet, and seven and a half inches diameter at top, and six at the bottom, and was charged with five hundred pounds of Sir Henry Bridge's double-strong blasting-powder. At half-past three, the match was lighted, and in three minutes the explosion took place. The report was not so loud as from a small piece of ordnance; but the effect that was produced was highly satisfactory to all the scientific gentlemen present, and completely fulfilled the expectations that had been conceived by the projector. At the moment of the explosion, the great mass of rock appeared to those at a short distance, to be forced upwards, and then to rend in large and deep fissures. It is calculated that upwards of twenty thousand tons of solid rock have been displaced by this experiment."*

In the United States of America, a patent has lately been taken out for facilitating the operation of boring rocks, which is thus described.—"A frame is made, in the centre of which an iron shaft or rod is caused to rise and fall vertically between friction rollers, so placed as to keep it in its position. In the lower end of the shaft, a socket is formed, to receive drills of different sizes. Provision is

* *Edinburgh Observer*, as quoted in the *Arcana of Science*, for 1835.

made for placing the machine vertically by sliding pieces upon each of its four legs, which serve to lengthen them as may be necessary. The apparatus, for working the shaft up and down, is formed as follows :—A circular plate of iron, about a foot in diameter, has a hole in its centre, provided with a socket adapted to the iron rod or shaft, and capable of being secured at any part of it, so that the plate will stand horizontally. At a little distance from the periphery of this plate, an iron spindle crosses the frame; upon this spindle are lifters, which, as it is turned by a crank, come in contact with the lower side of the plate, and raise the shaft; friction-rollers are contained within the lifters, to cause them to slide easily upon the plate, and their action is so managed as to produce a small revolution of the plate, and consequently of the drill, at every lift."*

Formation Level.—This is a subject of paramount importance, inasmuch as it constitutes the foundation upon which the stability of the road chiefly depends; it is, therefore, manifest, that every precaution to procure its uniformity, and to avoid irregularities is essential. Should indentations occur, they will act as receptacles for the accumulation of moisture, which will deteriorate the foundation of the road, and consequently augment the expense of maintaining it. Those defects, with all their concomitant evils, are yet further increased, should they occur where the cuttings are deep; as those places are generally in shade, being deprived of the benefit of the sun, a circumstance which militates considerably against the soundness of foundations.

**Journal of the Franklin Institute*, as quoted in Hebert's *Engineer's Encyclopædia*, Vol. 2, p. 371.

SLIPS AND DRAINAGE.—In the formation of railways, an enormous expense is often incurred, consequent on the removal of those huge masses of earth termed *slips*, which burst from the sides of the excavations; the baneful effects of which, it is presumed, have been noticed even by the most cursory observer. It may be necessary to remark, that the free-working blueish clay, so prevalent in this county, (Durham,) which is so much interspersed with vertical fissures, is, in general, the most subject to these disruptions, on account of the water inserting itself so readily into those places.

Drainage is one of the primary objects to be observed to establish a good and substantial foundation, whereon to form a railroad; it also materially tends to prevent the water from bursting the slopes; therefore, the greatest attention to it is absolutely necessary, as a trifling inadvertency in the outset will probably cause serious ulterior consequences.

Excavations in sloping grounds being so subject to be flooded by the water, when escaping from the rising grounds, particular care must be observed in diverting it from their high side, and when this desirable object cannot be accomplished—without too much expense—the water should be conveyed in drains down the slope into the bottom drainage, where convenient, or across the excavations, but on no pretence whatever, ought it to be allowed to flow down the slopes, as it is frequently the cause of disruptions taking place in them. And, wherever water is found to exist in the slopes, it is desirable to attain its source in the interior as soon as possible, and to introduce open rubble, or other drainage, branching in various oblique directions, communicating with the direct main drains, and ultimately with the open side drains at the bottom

of the cuttings. Piling the slopes is sometimes judicious, as are secondary piles wound with saughs, willows, &c., but where much water is found to exist, draining must be considered as the only effectual remedy.

The good effects of soiling and draining slopes, is fully exemplified on the Newcastle-upon-Tyne and Carlisle railway, in the great cut through the Cowran Hills, near the latter place; the cut being upwards of one hundred feet in depth, slopes two to each perpendicular foot; composed of various kinds of soil, and where there is not the least appearance of slipping in the slopes.

Dwarf-Walls.—To prevent the lower part of slopes in excavations, from being injured by atmospherical changes, recourse is frequently had to the building of what are termed *dwarf-walls*; and where slopes are much subjected to springs, their introduction is very essential. The method consists of building walls at the foot of the slopes, to the height of about three feet; or, a superior method, is that of displacing part of the earth from the foot of the slopes, and filling the vacuity with masonry corresponding with the batter of the slopes; in either case, leaving apertures at suitable distances for the egress of the water from the slope-drains. This latter mode has one great advantage over the former, that is to say, when a disruption takes place in the slope, it usually slides over the latter, leaving it undisturbed; whereas, the former, in most cases, by the same cause, would be precipitated into the ditch and intermixed with the loose earth.

Measuring Works.—In measuring excavations and embankments, it is advisable always to pursue one method, which tends greatly to facilitate calcula-

tions and also to prevent the occurrence of erroneous results, when, perhaps, there is not sufficient time on hand to allow of due consideration. The dimensions should also be taken so that they may be operated upon with the least number of figures, combined with as little trouble as possible; to obtain which, perhaps taking them in yards and decimal parts of a yard is as advantageous a mode as any; and for calculating, two places of decimals will suffice for all practical purposes.

In the annexed tablet we have both carried each number to four places of decimals and also in the third and last columns inserted the nearest two decimals to calculate with; that is to say, when the third decimal was less than ·005, it is altogether omitted, and, when it exceeds that number, ·01 is added to the second decimal.

One Yard the Integer.

Ft.	In.	Dcls.	Dcls	Ft.	In.	Dcls.	Dcls.
	1	·0278	·03	1	7	·5278	·53
	2	·0556	·06	1	8	·5556	·56
	3	·0833	·08	1	9	·5833	·58
	4	·1111	·11	1	10	·6111	·61
	5	·1389	·14	1	11	·6389	·64
	6	·1667	·17	2	0	·6667	·67
	7	·1944	·19	2	1	·6944	·69
	8	·2222	·22	2	2	·7222	·72
	9	·25	·25	2	3	·75	·75
	10	·2778	·28	2	4	·7778	·78
	11	·3056	·31	2	5	·8056	·81
1	0	·3333	·33	2	6	·8333	·83
1	1	·3611	·36	2	7	·8611	·86
1	2	·3889	·39	2	8	·8889	·89
1	3	·4167	·42	2	9	·9167	·92
1	4	·4444	·44	2	10	·9444	·94
1	5	·4722	·47	2	11	·9722	·97
1	6	·5	·5	3	0	1·	1·

When cuttings are to be of great magnitude, it is very desirable to measure the intended widths at intervals, and carefully note them down previous to commencing excavating, leaving corresponding marks at those places—knowing the distance of each from some stationary object, such as the fencing—to distinguish them hereafter, and to ascertain that the slopes *are* excavated to the measured breadths. It should also be observed whether the surface is higher any where than at the top of the intended slopes, and, if so, that part above should be ascertained, it being impossible to measure such apex when the excavation is completed.

Should the cubical content of embankments have to be ascertained by measuring them, the ground whereon they have to be formed ought to be measured and marked out similar to that for the preceding excavations, and if the surface be sloping transversely, sections of it should be prepared prior to any part of the embankments being deposited. If these instructions be attended to, much trouble and expense will be avoided, when the works have to be finally measured, as we have more than once experienced.

In ordinary excavations, the cubical content of a chain in length will be found with the least trouble by the following rule:—Add each top and bottom breadth together, and multiply each sum by its respective depth. Then add their two products together, and place a duplicate of the sum underneath, observing that it be removed one digit towards the left hand, (equal to multiplying by one-half of the length,) and one-half of the result will be the cubic content.

For all the succeeding chains in length the product of each latter breadth and depth is merely

required to be brought forward for each first product.

Rule 2.—In many excavations, the operation of measuring and calculating may be still more simplified. Thus, take an average dimension of each chain in length; add the top and bottom breadth together, and multiply that sum by the depth; place a duplicate of the product one digit towards the left hand, underneath, and the sum of these two products will represent the cubical content of each chain in length respectively.

Note.—For ascertaining the cubic content of embankments by either of the foregoing rules, the operation will be precisely similar to that of cuttings, only assuming the top and bottom breadths transposed.

EXAMPLES.

1.—Suppose a chain in length of cutting, to be of the following dimensions:—Breadth at formation level, 9 yards; depth at one end, 6·93, and breadth at top, 29·8 yards; and at the other end, 7·05, and breadth at top, 30·15 yards; what is the cubical content?

Bths. Depths. Products of Bths. & Dpth.

$$\begin{array}{l} 29{\cdot}8 \\ \underline{\ \ 9{\cdot}0} \\ 38{\cdot}8 \times 6{\cdot}93 = 268{\cdot}88 \\ \\ 30{\cdot}15 \\ \underline{\ \ 9{\cdot}00} \\ 39{\cdot}15 \times 7{\cdot}05 = \underline{276{\cdot}00} \\ \qquad\qquad\qquad\ \ 544{\cdot}88 \\ \qquad\qquad\qquad \underline{5448\ 8} \\ \qquad\qquad\qquad 5993{\cdot}68 \div \tfrac{1}{2} = 2996{\cdot}84 \text{ cub. yds.} \end{array}$$

2.—Suppose the dimensions of the adjoining chain to be as follows:—Breadth at formation level, 9 yards; depth at the end adjoining the above chain, 7·05, and breadth at top, 30·15 yards; and at the greater end, depth, 7·15, and breadth at top, 30·45 yards; what is the cubic content?

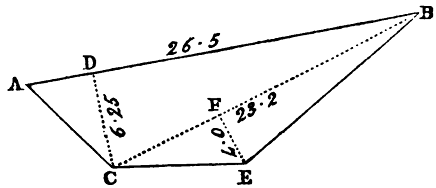
Bths. Depth. Product of Bths. & Dpth.
Last product, 276·00
30·45
9·00
39.45×7·15=282·07
558 07
5580 7
6138·77÷½=3069·38 cub. yds.

Rule 2.—*Example* 3.—Required the cubic content of one chain in length of cutting, the top breadth being 31·2 yards; that at the formation level the same as in the two preceding examples, and the depth 7·4 yards?

Bths. Dpth. Product of Bths. & Dpth.
31·2
9·
40·2×7·4=297·48
2974 8
3272·28 cub. yds.

When the surface of the ground slopes considerably in a transverse direction, as in the annexed diagram, at suitable distances, sections of the excavation must be made, or rather measured upon those taken at the commencement, (p. 55,) and the content found by measuring them in two triangles as shown on the following page.

Should an embankment, erected upon similar ground have to be measured, it is only to suppose the top and bottom of the diagram reversed.



A B 26·50×C D 6·25=165·63
C B 23·20×E F 4·00= 92·80

258 43
2584 3
2842·73 cubic yards.

When there is a difference between the section at each end of a chain, the foregoing rules are not strictly mathematically correct, nevertheless they are sufficiently accurate for practice, because, having found the sectional (double) area—and perhaps not the most complexly—the excavation may be divided longitudinally into as *short* portions as we please, which will cause each result to be a very close approximation to each true cubic content.

CHAPTER V.

HAULAGE.

Resistance opposed to the Motion of Carriages upon level Railroads—Power, Speed, and Distance of a Horse's Day's Work—Quantity of Work performed each Day by a Horse—Weight of Earth-waggons—Specific Gravity of Earth—Expenses attending Horse Power—Expense of Conveyance, per Cubic Yard, per Mile—The Tractive Force necessary to Ascend and Descend Planes, elucidated—Tables exhibiting the Useful Effect per Day of each Horse, in Tons and Cubic Yards of Earth, drawn one Mile; and also the Expense of Haulage per Ton, and per Cubic Yard, upon various Inclinations of Ascending and Descending Planes—Examples showing how the Tables are Calculated—Method of Calculating the Gross Load, and Useful Effect, that can be produced by any Motive Power on a Level, and on Ascending and Descending Planes.

Upon a railroad in good condition, the resistance to the motion of such carriages as are commonly used, is estimated equal to the 240th part of the insistent weight, or 9·33 lbs. per ton; that is to say, if the weight of a waggon and its load amounted to three tons, the traces of a horse drawing it would be stretched with a force equivalent to 28 lbs. An ordinary horse is considered to exert a tractive force of 150 lbs.,* when travelling at the rate of two and a half miles an hour; and the duration of his day's work at this speed is estimated at eight hours, or equal to twenty miles travelled per day. Whence we have $150\times240\times20=321$ tons, including carriages, transported one mile per day by each horse.

* "Mr. Bevan, whose results are much more entitled to confidence than those of any other experimentalist, on account of the much more extended scale of his experiments, estimates the power of a horse at 163 lbs. being the mean force exerted by each horse out of 144 at ploughing."—Hebert, p. 540.

But for temporary lines of railway, the friction must be computed at considerably more than the preceding, on account of the subsiding of the road, the quantity of extraneous matter upon the rails, and many other retardations incident to such undertakings; moreover, the wheels of earth-waggons—in order to keep the carriages low—being, in general, smaller than the wheels of other waggons, causes an additional friction; therefore, after making a reasonable allowance for these, and similar imperfections, we may, perhaps, assume correctly the resistance on the level to amount to the 150th part of the insistent weight.

The only benefit that arises by using low wheels—exclusive of the facility they afford in *loading*—being that of improving the angle of draught, is, in the present instance, rendered almost nugatory, owing to the load being conveyed in more carriages than one, which prevents any advantage resulting to the draught-line, except from the waggon immediately attached to the horse, that of the remaining part of the waggons being only horizontal.

Although twenty miles is usually assigned as the day's work of a horse when loaded, we may calculate a greater distance during the time he is employed in the transmission of excavated earth, as one-half of the space is traversed with the carriages empty. We shall, therefore, in the following disquisitions respecting horses, estimate their day's work at twenty per cent. more; equal to twelve miles travelling with the load, and twelve in drawing back the empty waggons. It may be necessary to state that even *less* than twenty miles is generally considered a day's work for common carting, an allowance attributable to the unavoidable loss of time in loading.

Taking the power of a horse at 150 lbs., we will then have 150×150×12=270,000 lbs. gross, removed one mile per day, and deducting one-fourth of it for the weight of the waggons, his performance per day will amount to 90·4 tons of earth transported one mile. The weight of a cubic yard of ordinary earth being about twenty-eight cwt. (19·29 cubic feet per ton, or one ton equal to five-sevenths of a cubic yard,) one horse will convey 64·57 cubic yards of soil one mile each day. Now, suppose we allow for horse-power and attendance seven shillings per day, the expense of conveyance per mile will amount to 1·3 pence per cubic yard.

There may, and probably will, be various opinions with regard to the formula we have adopted; but thus much may be said with certainty, that the sum of 1·3 pence per cube yard agrees very nearly with the results of our own practical experience. When the horse-power cost six shillings per day, the expense was usually about one penny per cubic yard per mile; and 6s. : 7s. : : 1d. : 1·17d., which is only $\frac{13}{100}$d. less than our result.

Although we have known works of great magnitude executed at the rate of six shillings per day, for horse-power and attendance, yet, at the present time, seven shillings per day is considered nearer the actual average cost.

It may, however, be proper to remark, that the cost of conveyance is not exactly proportionate to the distance; there are certain unavoidable contingencies where the earth is loaded, and also at the place of deposit, caused by hauling the waggons to and fro, placing and replacing them, stoppages, &c., the expense of which being commonly as much for a short distance, as for one of greater length.

We have already stated that on permanent railroads, the tractive power necessary to overcome the resistance on the level amounts to the 240th part of the weight moved, or 9·33 lbs. per ton. This resistance, caused by the attrition of the axles, and that of the wheels in collision with inequalities at the joints of the rails, conjunctively with their want of smoothness, is the same whether the road be level or inclined; therefore, in order to draw a weight up any inclination, it is to be overcome in addition to the tendency of the load to fall down the plane—a tendency in the exact proportion of the height of the plane to its length. Thus, a weight of 2240 lbs. when being drawn up an inclined plane of one in 240, or 22 feet per mile, has a tendency of the 240th part of one ton, or 9·33 lbs., to fall down the plane. It therefore requires a tractive power twice as great as a level; and, in short, for every additional twenty-two feet per mile that a plane rises, a tractive force of 9·33 lbs. per ton will be necessary for the ascent. It follows that an ascent of forty-four feet per mile would require *three* times the force of traction necessary upon a level; sixty-six feet per mile *four* times that force, and so on. In other words, any given power would only draw one-half the weight up an ascent of twenty-two feet to the mile, that it would draw along a level; one-third up an ascent of forty-four feet, and only one-fourth up an ascent of sixty-six feet to the mile.

But, upon temporary lines of railway where the resistance upon the level amounts to the 150th part of the weight, it would require a plane to be elevated to 35.2 feet per mile to double the tractive power on a level; 70·4 feet to treble it; and 105·6 feet per mile to cause the force of traction on the level to be quadruply increased.

Now, it is *vice versa* when drawing a weight down a plane, by the falling tendency of the load assisting the tractive force in overcoming the resistance, until the declination of the plane causes the gravitating force to be equivalent to the resistance upon the level; when, of course, the weight descends by itself.

EXAMPLES.

1.—Assuming the friction upon the level to amount to the 240th part of the weight, what power is necessary to draw one ton, (2240 lbs.,) up an inclination of 1 in 320?

2240÷240th pt.=9·33 lbs., friction on the level.
2240÷320 =7· gravity of plane.
16·33 lbs.=the power necessary to draw one ton up the inclination.

2.—The friction on the level being equal to the last example, what power would draw one ton down the same inclination?

9·33 lbs., friction on the level.
7· gravity of plane.
2·33 lbs.=the power necessary to draw one ton down the inclination.

The opposite tables exhibit the quantities removed by each horse per day, and also the expense of removal upon various inclinations of ascending and descending planes, agreeably with the foregoing estimation, namely, each horse exerting a tractive force of 150 lbs., and travelling twenty-four miles per day—twelve miles loaded, and twelve, drawing back the empty waggons.* Horse power and attendance, 7s. per day. Weight of waggons, $\frac{1}{4}$th of gross load; earth, twenty-eight cwt. per cubic yard; and resistance on the level $\frac{1}{150}$th part of the weight.

* Except the equalised plane and that of the two following ones in the table of descending planes, where the day's work is estimated at twenty miles.

Table of Ascending Planes.

Ascent of Plane per Chain.	Quantity of Earth drn. one Ml. pr. Day.		Expense per Mile, in Pence, and Decimals.	
Inches.	Tons.	Cub. Yds.	Per Ton.	Per Cb. Yd.
LEVEL	90·40	64·57	0·929	1·301
0·5	82·58	59·00	1·017	1·424
1·0	76·01	54·29	1·105	1·547
1·5	70·40	50·29	1·193	1·670
2·0	65·56	46·83	1·281	1·794
2·5	61·35	43·82	1·369	1·917
3·0	57·65	41·18	1·457	2·040
3·5	54·37	38·83	1·545	2·163
4·0	51·43	36·74	1·633	2·286
5·0	46·43	33·17	1·809	2·533
6·0	42·32	30·23	1·985	2·779
8·0	35·94	25·67	2·337	3·272

Table of Descending Planes.

Descent of Plane per Chain.	Quantity of Earth drawn one Mile per Day.		Expense per Mile, in Pence, and Decls.	
Inches.	Tons.	Cub. Yds.	Per Ton.	Pr Cb. Yd.
LEVEL	90·40	64·57	·929	1·301
0·5	96·40	68·86	·871	1·220
1·0	104·42	74·59	·804	1·126
1·5	115·10	82·21	·730	1·022
2·0	129·54	92·53	·648	·908
2·5	149·62	106·87	·561	·786
3·0	179·28	128·05	·469	·656
3·168	188·33	134·53	·446	·624
3·5	181·22	129·44	·464	·649
4·0	171·45	122·46	·490	·686
5·0	185·73	132·66	·452	·633
6·0	169·27	120·90	·496	·695
8·0	143·77	102·69	·584	·818

It is to be understood that on the ascending planes, the earth is conveyed up the inclination, while on the descending planes, it is *vice versa*.

On steep ascending planes such as those in the latter part of the first table—when the road is firm and safe, the gravity of the plane being sufficient both to counterbalance the resistance to the motion of the *empty* waggons and to cause their descent, conveying the horses with them—considerable power may be gained, and, consequently, the expense of removal decreased; but it was considered unnecessary to calculate that augmentation of power for the ascending table, on account of its results being intended for general purposes. Neither was it deemed requisite to increase the useful effect for the difference between drawing the empty waggons down the planes—or even on planes where the empty waggons descend by gravity—and that of drawing them along a level. It is sufficient to say that any of the quantities in the first table are equivalent to 90·4 tons of earth drawn one mile per day along a level; the empty waggons returned forming no part of such calculations.*

The days' work for the second table—until the planes exceed 3·168 inches per chain, which equalises the draught—is calculated as explained in the second example (page 83.) The descending table shews the maximum effect produced on planes descending 3·168 inches per chain (one in 250) and as the degree of descent increases, the diminution of that effect, in proportion to the sine of inclination. Of course, a horse can draw a greater weight down the latter planes in the table, than he can draw down the plane of one in 250; yet he cannot draw

* Vide the first example p. 83.

so great a weight up them, as when ascending the equalised plane:—hence the maximum effect produced upon the last mentioned inclination.

In consequence of the horse exerting a tractive force of 150 lbs. in each direction upon the equalised plane, we have estimated a distance of ten miles in each direction for his day's work when employed upon that gradient.

When the inclination of the descending plane exceeds that whereon the tractive power is equalised, the useful effect is regulated by the weight of the empty waggons drawn up the plane; our ratio of waggons is computed at the fourth part of the gross load; consequently, the weight of the earth drawn down the plane is equal to three times the weight of the empty waggons drawn up it, per day; which latter weight is assigned in the second table for a horse's day's work.

Upon the plane descending at the rate of 3·5 inches per chain, the horse exerts a tractive force of 150 lbs. in returning the empty carriages, and 91·22 lbs. in drawing them when loaded; and on the following plane he exerts the same power (150 lbs.) when returning them empty, and 62·06 lbs. in drawing them when loaded; while, on the level, he exerts a force of 150 lbs. in one direction, and only 37·5 lbs. in the other; therefore, for the two descending planes, we have only estimated the same length for his day's work as that of the equalised plane.

On the gradient descending at the rate of five inches per chain, a tractive power of only 12·27 lbs. is requisite to draw the loaded waggons; and upon the last two planes in the table, the loaded waggons will descend by gravity, the horses having only to *walk* the distance; as on temporary lines of railroad

we consider it imprudent to cause the animals to be conveyed, lest serious accidents should befall them. We have made no addition to the useful effect for these three planes, for the difference either between the horse exerting a force of 12·27 lbs.—or walking one-half of the entire distance, as on the two last planes—and that of his exerting a force of 37·5 lbs. when drawing the empty carriages along the level.

It will be perceived that the friction of the empty carriages is estimated at the 150th part of their weight; which however is not precisely the case, it being rather more on account of resistance to motion increasing in rather less ratio than weight; although such difference is scarcely perceptible in practice.

We shall now proceed to explain the method of estimating the performance of horses, when they are employed upon a level, upon ascending, and descending planes.

For the level plane:—

The power$\times$resist. on the level$=$the weight drawn along the level.

For the ascending plane:—

$$\frac{\text{The pr.}\times\text{wt. drawn upon the level}}{\text{resist. on level}+\text{gravity of plane}}=\text{the weight drawn up the plane.}$$

For the descending plane:—

$$\frac{\text{The pr.}\times\text{weight drawn on the level}}{\text{resist. on level}-\text{gravity of plane}}=\text{the weight drawn down the plane.}$$

Note.—The effect produced upon planes of the above description may be calculated decimally with great facility, as shown in the explanations to the following tables of resistance, in the latter part of the present chapter.

EXAMPLES.

1.—Suppose a horse be employed on a gradient ascending at the rate of two inches per chain; what will be the result of his day's work? power, friction, &c., as stated in p. 78.

Pr. $150 \times 150 = 22{,}500$ lbs.,=the weight drawn upon the level, and two inches per chain=1 in 396 or $\frac{1}{396}$th part of 22,500 lbs. is to be added to the friction on the level, for gravity of plane.

$22{,}500 \div \overset{\text{th. pt.}}{150} = 150$ lbs., friction on the level.

and, $22{,}500 \div 396 = \underline{56{\cdot}82}$ grav. of plane.
$206{\cdot}82$ lbs. total resistance.

and, $\frac{150 \times 22{,}500}{206{\cdot}82} = 16{,}318{\cdot}53$ lbs.=the weight drawn at one time$\times$12 mls. trav. loaded=195,822 lbs. gross —$\frac{1}{4}$th for wgs.=146,866 lbs.=the weight of earth drawn one mile per day.

$146{,}866 \div 2240 = 65{\cdot}56$ tons drawn 1 mle. per day.

$146{,}866 \div 3136 = 46{\cdot}83$ cub. yds. drn. 1 mle. per day.

7s.$\div 65{\cdot}56 = 1{\cdot}281$ pence per ton per mile.

7s.$\div 46{\cdot}83 = 1{\cdot}794$ pence per cub. yd. per mile.

2.—If a horse be employed upon an inclination, descending at the rate of one and a half inches per chain, or 1 in 528; what will be the result of his day's work? Power, friction, &c., as in the preceding example.

Pr. $150 \times 150 = 22{,}500$ lbs.=the weight drawn upon the level; and for the plane descending 1 in 528; $\frac{1}{528}$th part of 22,500 lbs. is to be deducted for gravity of plane, from the friction on the level.

$$\begin{aligned} & 150 \text{ lbs. friction on the level.} \\ \text{and, } 22{,}500 \div 528 = & \ \underline{42{\cdot}61} \text{ gravity of plane.} \\ & 107{\cdot}39 \text{ lbs. total resistance.} \end{aligned}$$

then, $\frac{150 \times 22{,}500}{107{\cdot}39} = 31{,}427{\cdot}51$ lbs.=the weight drawn down the plane.

On the level plane, the horse returns with empty waggons—amounting to one-fourth of the gross weight in the loaded direction, or 5625 lbs.—but it would require additional power to draw one-fourth of the above descending load, (31,427·51 lbs.,) *up* this plane of 1 in 528. Therefore, we must estimate a number of waggons drawn up this plane equivalent in weight to 5625 lbs. drawn on the level; which, being added to the gross downward load, will be equal to a whole journey to and fro, on the level.

Now, a power of 150 lbs. draws 22,500 lbs. upon the level; hence a power of 37·5 lbs. will draw 5625 lbs. upon it.

$$\begin{aligned} 5625 \div 150\text{th pt.} &= 37{\cdot}5 \text{ lbs. friction on the level.} \\ 5625 \div 528 &= \ \underline{7{\cdot}1} \text{ gravity of plane.} \\ & \quad 44{\cdot}6 \text{ total resistance.} \end{aligned}$$

then, 44·6 : 37·5 : : 5625 : 4380·84 lbs.=the weight of the empty waggons drawn up the plane.

and, 31,427·51+4380·84=35,808 lbs.×12 miles= 192 tons=the total weight drawn one mile per day.

The weight of the earth waggons being=to $\frac{1}{4}$th of the gross weight when loaded; $\frac{1}{5}$th of this 192 tons will be absorbed by returning the empty waggons, and also another fifth by the waggons carrying the downward load; leaving 115 tons, or 82·21 cubic yards of earth, drawn down the plane one mile for the horse's day's work.

The weight of empty waggons drawn up the

plane equivalent to 5625 lbs. drawn along the level may likewise be found in the following manner ;—

150 lbs., friction on the level, and
42·61 gravity as before.
192·61 lbs., total resistance.

and, 192·61 : 150 lbs. pr. : : 5625 : 4380 lbs.=the weight of the empty waggons drawn up the plane of one in 528, as on the eighty-fourth page.

CHAPTER VI.

HAULAGE, CONTINUED.

Advantages and Disadvantages of employing locomotive and fixed machinery, for the removal of earth-works—Locomotive and Stationary Engine planes —Elucidation of that plane upon which the maximum Effect is produced by Animal power—Method of estimating the Average distance of leading earth-work—Tables exhibiting the Resistance opposed to the motion of Carriages upon various Inclinations of Ascending and Descending planes; also Examples explanatory of their use—Tables of the Resistance of various kinds of Roads, and Granite Tramways—Tables showing the comparative Weights drawn, and the corresponding Expense upon such roads—Proper Inclination for a Descending Trade for each kind of road—Effect of the Inclinations, with their relative Expense—Patent axle Grease, and Lubricating Fluid, &c., &c.

The several calculations in the last chapter relate to horse power, which is chiefly used, when constructing railways, and often attended with the least expense; but where works are of great magnitude, the application of mechanical power is to be preferred. Where the blocks are imbeded in clay, or other retentive soils, in order to free the rails from the weight of the motive power—or where gradients are steep—fixed machinery is indispensable. But, where hard material can be procured at a reasonable expense, to form and repair the road; or where the earth is to be drawn along permanent lines, locomotive power may be introduced successfully, as it is decidedly preferable to fixed machinery, on account of the greater facility with which it can be applied, as the length of cutting

and embankment becomes increased. It tends also to consolidate embankments, before fixing the permanent rails.

When the mechanical power is *locomotive*, the maximum effect is produced on gradients where the draught is equalised; but, should the power be *fixed*, it will be produced where the declination gives the load a preponderance of weight to descend the plane, drawing a rope or chain to enable the engine at the summit, to draw back the empty carriages.

It has been previously stated in page 80, that the maximum effect of animal power is obtained on inclined planes, where the tractive force is equalised: there is however one exception, which we now proceed to illustrate.

On permanent lines, or where the road is firm, and can be made safe, and kept in good order, the maximum effect will be produced on planes where the loaded waggons have just the requisite gravity to cause their descent at a moderate uniform velocity, and *convey* the horses with them. This, of course, renders a greater tractive force necessary to return the empty waggons; but, at the same time, it must be borne in mind that on such planes animal labour is spared for one-half of the distance traversed—an advantage which far more than counterbalances its extra exertion on returning.

We observe, in practice, the loaded coal-waggons —which are considered equivalent to 240 times the weight of the moving power—to descend planes of 3·5 inches per chain rather too freely, or with an accelerated velocity. Hence it appears, that an additional elevation of plane equal to 0·2 inches per chain—added to the plane where the gravity equals the resistance on the level—is more than sufficient to gravitate them, at a moderate uniform speed.

But, suppose we allow the additional sine of inclination of 0·2 inches per chain—equal to one in 3960—to cause the descent of loaded waggons during unfavourable weather, and applying the formula to temporary lines, where the friction on the level$=\frac{1}{150}$th part of the weight, we then have $\frac{1}{3960}+\frac{1}{150}=\frac{1}{144\cdot5}$, or a plane descending one in $144\frac{1}{2}$.

Now, the horse by exerting a tractive force of 150 lbs. draws a weight of 6·28 tons of earth-waggons up the equalised plane, ten miles per day; he also exerts the same force in drawing a gross load of four times that weight, for ten miles down it= 188·33 tons of earth drawn down one mile per day, by a tractive force of 150 lbs., exerted for the length of twenty miles. On the plane of one in 144·5, when exerting the above force, he will only draw up 4·93 tons of earth-waggons, yet he will travel twice that distance, or twenty miles up the ascent with them per day, on account of his being *conveyed* down the plane by its gravity, and only exerting his tractive power of 150 lbs. in one direction. This makes the distance walked, and the tractive power exerted by the horse for a day's-work on such a plane, equivalent in length and draught to that of the equalised one. Assuming the weight of the carriage for conveying the horse to amount to 6·67 cwt. we will then have 4·6 tons of earth-waggons drawn up the plane each time=338·4 tons of earth drawn down it one mile per day; which is 79·68 per cent. more than on gradients where the draught is equalised.

But, suppose one-tenth of the 338·4 tons to be absorbed by the additional *time* the horse is employed, and for extra allowance to the attendant, we still have 304·56 tons of earth conveyed one

mile per day, by each horse, on inclinations of this description, being 61·72 per cent. more than upon equalised ones. We should not have resumed and dwelt with such apparent prolixity upon this subject, had we not felt that its importance merited more consideration, where animal power is to be employed, than that it has yet generally received.

AVERAGE LEADAGE.—Having ascertained the inclination of the road, in order to know what weight of earth can be drawn at one time, the next question which arises is the average distance that the whole will have to be led. The common practice of adding one-half of the length of the cut, and one-half the length of the embankment together for the average leadage, answers the purpose when the depth of the cut and the height of the embankment are somewhat regular; but should they, or either of them, vary in their depth or height as shown in the following section, this method is then incorrect. Thus, half the length of the excavation in page 91, is seventeen chains, and half the length of the embankment is fourteen, making thirty-one chains for the average leadage; whereas, it is shown in the same page, that it should be forty-three chains. Now, were the cut deepest at *a*, and the extra quantity of *a* to be deposited in *F*, the error would be yet greater, as the average distance would not be increased by calculating it in this manner.

It will be apparent to the reader, that by the quantity being increased at *a* and deposited in *F*, it must necessarily lengthen the average distance of the whole; and, suppose the cut to be deepest at instead of at *a*, it would shorten it, and yet more so, were the embankment highest at *c*, instead of at *F*; but, by the former method of calculating, the average distance is in all cases the same; it is therefore manifestly erroneous.

N

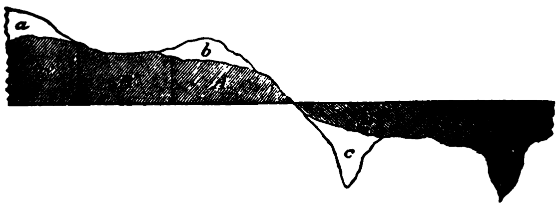
When the quantity of earth is considerable, or a great distance to be removed, the average length becomes important; and therefore it should be calculated with the greatest accuracy. Those who are conversant with the subject easily determine a length sufficiently accurate for practice; but cases frequently occur when the precise average length is required, or at least a close approximation to it. For this purpose, we would suggest the following method.

Divide the length of the embankment into separate portions, according to the irregularity of its height, as shown at *D*, *E*, and *F*, and ascertain, (from the excavation tables in a subsequent part of this work,) their respective cubical contents. Next measure the depth of the cutting at *A*, and in the same table it will be readily seen what length of *A* is requisite to complete *D*; or, if the cut be very irregular in its depth, it may be taken in different lengths until they will produce a sufficiency for the completion of *D*. The parts *B* and *C* are similarly calculated. Multiply the cubic content of each piece of cut—by the sum of half its length, half the length of each corresponding piece of embankment, and the whole length of each intervening portion of cut and embankment. Add their products together, and divide the aggregate by the total number of cubic yards in the cut, the quotient will be the average distance that the whole will have to be conveyed.

Example.—In the subjoined section, the contents of the embankment are as follows,—*D*, 7000; *E*, 17,800; and *F*, 25,600 cubic yards;—their lengths are 12, 10, and 6 chains respectively, and the several portions of cutting to form the same are

	Cubic yds.		Chains.
A	7,000	and its length	15
B	17,800	....	11
C	25,600	....	8

required the average distance that the whole will have to be conveyed?



A 15+*D* 12=27÷½= ....13½ chains.

B 11+*E* 10=21÷½=10½ chains, and will have to be conveyed through *A*, and *D*; therefore 10½+*A* 15+*D* 12= ....37½ chains.

C 8+*F* 6=14÷½=7 chains, and will have to be conveyed through *B*, *A*, *D* and *E*; therefore 7+*B* 11 +*A* 15+*D* 12+*E* 10= ....55 chains.

then 7,000×*A*13½= 94500
17,800×*B*37½= 667500
25,600×*C*55 =1408000
2,170,000÷50,400=43 chns.= the average distance that the whole will have to be led.

Note.—The three multipliers 13½, 37½, and 55 chains, is the average distance that *A*, *B*, and *C*, have to be led respectively.

In the above section *C* does not appear to be so much larger than *A*, as it is in reality, on account

of the cubical contents advancing in so much greater ratio than the depth; which may be illustrated by the subjoined example. One chain in length of cutting five feet in depth contains three hundred and ninety-one cubic yards; the same length if ten feet in depth, would contain nine hundred and four; if twenty feet deep, two thousand two hundred and ninety eight; and if forty feet in depth, it would contain six thousand five hundred and fifty-one cubic yards.* Moreover, the disparity between the cubical content and the depth, would be considerably greater, if the latter depth of cut was executed —as it should be—to a flatter slope.

* Vide first table of excavations, slopes one to one.

Table showing the Resistance opposed to the Motion of a Carriage on different Inclinations of Ascending Planes; the Friction on the Level being estimated at the 240th part of the Weight.

	Inclination of the Plane equal to 1, in									
	0	100	200	300	400	500	600	700	800	900
0	·00417	·01417	·00917	·0075	·00667	·00617	·00583	·00559	·00542	·00528
10	·10417	·01326	·00893	·00739	·0066	·00613	·0058	·00557	·0054	·00526
20	·05417	·0125	·00871	·00729	·00655	·00609	·00578	·00555	·00538	·00525
30	·0375	·01186	·00851	·0072	·00649	·00605	·00575	·00553	·00537	·00524
40	·02917	·01131	·00833	·00711	·00644	·00602	·00573	·00552	·00536	·00523
50	·02417	·01083	·00817	·00702	·00639	·00598	·0057	·0055	·00534	·00522
60	·02083	·01042	·00801	·00694	·00634	·00595	·00568	·00548	·00533	·00521
70	·01845	·01005	·00787	·00687	·00629	·00592	·00566	·00546	·00531	·0052
80	·01667	·00972	·00774	·0068	·00625	·00589	·00564	·00545	·0053	·00519
90	·01528	·00943	·00761	·00673	·00621	·00586	·00561	·00543	·00529	·00518

Table showing the Resistance opposed to the Motion of a Carriage on different Inclinations of Ascending Planes; the Friction on the Level being estimated at the 200th part of the Weight.

	Inclination of the Plane equal to 1, in									
	0	100	200	300	400	500	600	700	800	900
0	·005	·015	·01	·00833	·0075	·007	·00667	·00643	·00625	·00611
10	·105	·01409	·00976	·00823	·00744	·00696	·00664	·00641	·00623	·0061
20	·055	·01333	·00955	·00812	·00738	·00692	·00661	·00639	·00622	·00609
30	·03833	·01269	·00935	·00803	·00733	·00689	·00659	·00637	·0062	·00608
40	·03	·01214	·00917	·00794	·00727	·00685	·00656	·00635	·00619	·00606
50	·025	·01167	·009	·00786	·00722	·00682	·00654	·00633	·00618	·00605
60	·02167	·01125	·00885	·00778	·00717	·00679	·00652	·00632	·00616	·00604
70	·01929	·01088	·0087	·0077	·00713	·00675	·00649	·0063	·00615	·00603
80	·0175	·01056	·00857	·00763	·00708	·00672	·00647	·00628	·00614	·00602
90	·01611	·01026	·00845	·00756	·00704	·00669	·00645	·00627	·00612	·00601

Table showing the Resistance opposed to the Motion of a Carriage on different Inclinations of Ascending Planes; the Friction on the Level being estimated at the 150*th part of the Weight.*

	Inclination of the Plane equal to 1, in									
	0	100	200	300	400	500	600	700	800	900
0	·00667	·01667	·01167	·01	·00917	·00867	·00833	·00809	·00792	·00778
10	·10667	·01576	·01143	·00989	·00911	·00863	·00831	·00807	·0079	·00776
20	·05667	·015	·01121	·00979	·00905	·00859	·00828	·00805	·00789	·00775
30	·04	·01436	·01101	·0097	·00899	·00855	·00825	·00804	·00787	·00774
40	·03167	·01381	·01083	·00961	·00894	·00852	·00823	·00802	·00786	·00773
50	·02667	·01333	·01067	·00952	·00889	·00848	·0082	·008	·00784	·00772
60	·02333	·01292	·01051	·00944	·00884	·00845	·00818	·00798	·00783	·00771
70	·02095	·01255	·01037	·00937	·00879	·00842	·00816	·00796	·00782	·0077
80	·01917	·01222	·01024	·0093	·00875	·00839	·00814	·00795	·0078	·00769
90	·01778	·01193	·01011	·00923	·00871	·00836	·00812	·00793	·00779	·00768

Table showing the Resistance opposed to the Motion of a Carriage on different Inclinations of Ascending Planes; the Friction on the Level being estimated at the 100th part of the Weight.

	Inclination of the Plane equal to 1, in									
	0	100	200	300	400	500	600	700	800	900
0	·01	·02	·015	·01333	·0125	·012	·01167	·01143	·01125	·01111
10	·11	·01909	·01476	·01323	·01244	·01196	·01164	·01141	·01123	·0111
20	·06	·01833	·01455	·01313	·01238	·01192	·01161	·01139	·01122	·01109
30	·04333	·01769	·01435	·01303	·01233	·01189	·01159	·01137	·0112	·01108
40	·035	·01714	·01417	·01294	·01227	·01185	·01156	·01135	·01119	·01106
50	·03	·01667	·014	·01286	·01222	·01182	·01154	·01133	·01118	·01105
60	·02667	·01625	·01385	·01278	·01217	·01179	·01152	·01132	·01116	·01104
70	·02429	·01588	·0137	·0127	·01213	·01175	·01149	·0113	·01115	·01103
80	·0225	·01556	·01357	·01263	·01208	·01172	·01147	·01128	·01114	·01102
90	·02111	·01526	·01345	·01256	·01204	·01169	·01145	·01127	·01112	·01101

Table of Descending Planes, showing the Resistance opposed to the Motion of a Carriage on different Inclinations of Descending Planes; the Friction on the Level being estimated at the 150*th part of the Weight.*

	Inclination of the Plane equal to 1, in								
	100	200	300	400	500	600	700	800	900
0	......	·00167	·00333	·00417	·00467	·005	·00524	·00542	·00556
10	......	·00191	·00344	·00423	·00471	·00503	·00526	·00543	·00557
20	......	·00212	·00354	·00429	·00474	·00505	·00528	·00545	·00558
30	......	·00232	·00364	·00434	·00478	·00508	·0053	·00546	·00559
40	......	·0025	·00373	·00439	·00482	·0051	·00532	·00548	·0056
50	0	·00267	·00381	·00444	·00485	·00513	·00533	·00549	·00561
60	·00042	·00282	·00389	·00449	·00488	·00515	·00535	·0055	·00563
70	·00078	·00296	·00396	·00454	·00491	·00517	·00537	·00552	·00564
80	·00111	·0031	·00404	·00458	·00494	·0052	·00538	·00553	·00565
90	·0014	·00322	·0041	·00463	·00497	·00522	·0054	·00554	·00566

The preceding tables exhibit the risistance opposed to the motion of a carriage on various inclinations of ascending and descending planes, from 1 in 10, to 1 in 990. They will be found very useful in abridging calculations either for horse power, or where the motive power is mechanical.

To ascertain the weight any given power would draw up, or down a plane:—Divide the power by the friction given in the ascending or descending tables; adding *as many* cyphers to the power for a dividend, as there are decimals contained in the divisor; and the quotient will be the weight drawn up, or down the plane.

Examples.—What weight will a tractive power of 150 lbs. draw up a plane of 1 in 340, the resistance being estimated=240th part of the insistent weight?

Look in the left side column of the first table, for 40, and for 300 at the top, and where these columns meet will be found the resist. ·00,711.

then, 150·00,000÷00,711=21,097 lbs.=the weight drawn up the plane.

Suppose a horse to be employed on a gradient descending one in 250; that he exerts a tractive force of 150 lbs., and travels twenty miles per day, (ten miles loaded and ten when empty); the weight of the waggons $\frac{1}{4}$th. of the gross load, and of earth 28 cwt. per cubic yard. Friction on the level $\frac{1}{150}$th part of the gross load.—What will be the result of his day's work?

Look in the left side column of the table in page 97 for 50, and for 200 at the top, and where these columns meet, will be found the resistance ·00267.

then 150·00,000÷·00267=56,180 lbs.=the weight drawn down the plane at one time.

and 56,180×10 miles loaded=561,800 lbs.—$\frac{1}{4}$th for

waggons=421,350 lbs. drawn one mile per day.
and 421,350÷2240=188·10 tons drn. 1 mile per day
or 421,350÷3136=134·36 cu. yds. drn. 1 ml. p. day

Note.—The actual quantity of earth drawn one mile per day by the above horse would be 188·33 tons, or 134·53 cube yards, as stated in the descending table (p. 79). The results here being a trifle less, are caused by the recurring decimal ·002,666, which is inserted in the table ·00,267. We have invariably throughout this work placed the last recurring decimal one more when it exceeded 5, which will answer best for all practical purposes; in some cases it makes the quantity appear rather more, in some rather less, as in this instance.

When the weight which a tractive power will draw along a level is given to find the weight which it will draw up or down any plane—

$\frac{\text{Resist. on level} \times \text{given wt.}}{\text{resist. of plane.}}$=weight which the tractive power will draw up, or down the plane.

Example.—If a horse draw 36,000 lbs. on a level, the friction being estimated at the 240th part of the weight upon it, what weight will he draw up a plane of one in 240?

In the second column of the first table opposite 0, will be found the resistance on the level ·00,417. Then look in the first column for 40, and for 200 at the top, and where these columns meet will be found the resistance of the plane ·00,833.

then ·00,833 : ·00,417 :: 36,000 : 18,021 lbs.=the weight which he can draw up the plane.

Note.—18,000 lbs. is the exact weight which he can draw up the plane; the trifling discrepancy occurs from the cause before referred to.

Table showing the Resistance opposed to the Motion of Carriages on different Inclinations of Ascending or Descending Planes, from 1 *in* 10 *to* 1 *in* 990 *; whatever part of the insistent weight they are drawn by.*

		100	200	300	400	500	600	700	800	900
		·01	·005	·00333	·0025	·002	·00167	.00143	·00125	·00111
10	·1	·00909	·00476	·00322	·00244	·00196	·00164	.00141	·00123	·0011
20	·05	·00833	·00454	·00312	·00238	·00192	·00161	.00139	·00122	·00109
30	·03333	·00769	·00435	·00303	·00232	·00189	·00159	.00137	·0012	·00107
40	·025	·00714	·00417	·00294	·00227	·00185	·00156	.00135	·00119	·00106
50	·02	·00667	·004	·00286	·00222	·00182	·00154	.00133	·00118	·00105
60	.01667	·00625	·00385	·00278	·00217	·00178	·00151	.00131	·00116	·00104
70	·01429	·00588	·0037	·0027	·00213	·00175	·00149	.0013	·00115	·00103
80	·0125	·00555	·00357	·00263	·00208	·00172	·00147	.00128	·00114	·00102
90	·01111	·00526	·00345	·00256	·00204	·00169	·00145	.00126	·00112	·00101

The opposite table shows the resistance opposed to the motion of carriages on different inclinations of ascending or descending planes, from 1 in 10, to 1 in 990; whatever part of the insistent weight they are drawn by. Thus, to ascertain what weight a tractive power of 150 lbs. would draw up a plane of 1 in 340, the resistance on the level being estimated=240th part of the weight?

Look in the left side column for 40, and for 200 at the top, and where these columns meet will be found the resistance on the level, ·00,417 (=240th part of the weight). Opposite, in the adjoining column (300) will be found the gravity of the plane ·00,294; add these two sums together for the total resistance, which will amount to ·00,711. Divide the given power by it, adding *as many* cyphers to the given power for a dividend, as there are decimals contained in the divisor, and the quotient will represent the weight drawn up the plane.

thus, 150·00,000÷·00,711=21,097 lbs.,=the weight drawn up the plane.

2.—What weight would the tractive force of 150 lbs. draw down the same plane, the friction on the level being equal to the above plane?

Proceed as in the last example, except that the total resistance is found by deducting the gravity of the plane from the friction upon the level.

Friction on the level, ·00,417
Gravity of the plane, ·00,294
·00,123 lbs =total resistance.

then, 150·00,000÷·00,123=121,951 lbs.,=the weight drawn down the plane.

3.—If a horse draw 36,000 lbs. upon the level, estimating the friction at the 240th part of the

weight upon it, what weight will he draw up a plane ascending at the rate of 1 in 240?

$\frac{\text{Resist. on level} \times \text{given wt.}}{\text{Total resistance.}}$=weight which he will draw up the plane.

Friction on the level, $\frac{1}{240}$th part='00,417
Gravity of plane, $\frac{1}{240}$th part='00,417

00,834 lbs.=total resistance.

and, '00,834 : '00,417 : : 36,000 : 18,000 lbs.=the weight which he can draw up the plane.

4.—Suppose a horse draws 36,000 lbs. upon a level, estimating the friction as on the preceding planes, (240th,) what weight will he draw down a descent of 1 in 340?

Find the total resistance as in example 2.

then, '00,123 : '00,417 : : 36,000 : 122,048 lbs.,= the weight drawn down the plane.

Note.—This result and that of example the second would have been alike, but for the reason stated in page 99.

5.—If a horse draws 122,048 lbs., down a descent of 1 in 340, how many pounds will he draw along a level. Friction as before (240th)?

$\frac{\text{Total resist.} \times \text{given wt.}}{\text{Resist. on level}}$=the wt. drawn along the level.

Find the total resistance as in example 2.

then, $\frac{\cdot 00,123 \times 122,048}{\cdot 00,417}$=36,000 lbs.=the weight drawn along the level.

6.—Supposing the friction on the level to amount to the 240th part of the weight, and a horse to draw 18,000 lbs., up a plane of 1 in 240, how many pounds will he draw upon the level?

Find the total resistance as in example 3.

then, '00,417 : '00,834 : : 18,000 : 36,000 lbs.=the weight drawn upon the level.

Granite Tramways, Paved and Common Roads.—From the evidence of several eminent engineers before the select committee of the House of Commons upon steam carriages, in 1831, it is apparent that the feet of horses are considerably more destructive to roads than the wheels of carriages. Mr. Gordon calculated that a set of tires would run three thousand miles in good weather; or, on the average, two thousand seven hundred miles; but that a set of horse's shoes would travel only two hundred miles. And Mr. Macneil estimated that in drawing coaches at great velocities, the injury to the roads by the horses was three times that of the wheels. The following is that gentleman's estimate:—

COACHES.		WAGGONS.	
Atmospheric changes	20	Atmospheric changes	20·
Coach-wheels	20	Waggon-wheels	35·5
Horses' feet	60	Horses' feet	44·5
	100		100·0

By employing an improved dynamometer, Mr. M. also practically ascertained the tractive force necessary to draw a carriage upon different kinds of roads. His general results are stated to be as follows:—

WEIGHT OF WAGGON, 21 CWT.

No. 1.	On Gravel road, the draught is	147 lbs.
2.	,, Broken stone surface, or old flint road,	65
3.	,, Broken stone road, on a rough pavement foundation	46
4.	,, Broken stone surface, upon a bottoming of concrete formed of Parker's cement and gravel,	46
5.	,, Well made pavement	33

Table exhibiting the performance of a Horse per day, and also the corresponding expense per ton, per mile, upon the preceding kinds of Roads; a Granite Tramway; and upon that of a Railroad.

Nos. and Friction as before.		Corresponding Friction.		Total mass moved one mile per day.	Useful effct drawn one mile per day.	Expense per ton per mile, in pence.
	Pounds per 21 cwt.	In lbs. per ton.	In parts of weight.	Tons.	Tons.	d.
No. 1	147	140·	$\frac{1}{16}$	21.43	16·07	5·227
2	65	61·90	$\frac{1}{36 \cdot 18}$	48·46	36·35	2·311
3 & 4	46	43·81	$\frac{1}{51 \cdot 13}$	68·48	51·36	1·636
5	33	31·43	$\frac{1}{71 \cdot 27}$	95·45	71·59	1·173
Tramway.	23·52	22·40	$\frac{1}{100}$	133·93	100·45	·836
Railroad·	9·80	9·33	$\frac{1}{240}$	321·43	241·07	·348

In the above table the power of a horse is estimated at 150 lbs., when travelling at the rate of two and a half miles per hour; and the duration of his day's work is reckoned at eight hours, equal to twenty miles per day. We have deducted one fourth of the gross load for the weight of the carriages, and allowed for horse-power and attendance seven shillings per day. The resistance to the motion of carriages upon railroads is inserted at the 240th part of the insistent weight, the friction now usually assigned to that species of road; that of the granite tramways is inserted at the 100th part which is the resistance allotted to such roads by different engineers; and also by Mr. Gordon in his work on *Elemental Locomotion*, selected from the reports of the Holyhead Road Parliamentary Committee.

It should be observed that the table represents the maximum quantity, and, consequently, the minimum expense; whereas in the transport of

merchandise, it frequently happens that the carriages traverse a great part of the road *empty*, hence, a material diminution of work, which necessarily increases the rate of tonnage.

Table showing the proper Inclination for a Descending Trade upon the foregoing Roads; the effect produced by a Horse upon them per day, on a Level, and upon the Proper Inclination; also the corresponding expenses per ton per mile.

Nos. and Friction as before.			On a Level.			On a proper Inclination.			
	In lbs. per Ton.	In parts of weight.	Total mass moved one mile per day.	Useful effect drawn one mile per day.	per ton per mile.	Proper inclination for a descending trade.	Total mass moved one mile per day.	Useful effect drn. one mile per day.	Expense per ton per mile
			tons.	tons.	d.	One, in	tons.	tons.	d.
No. 1	140·	$\frac{1}{16}$	12·86	9·64	8·712	26·67	32·15	24·10	3·485
2	61·90	$\frac{1}{36 \cdot 18}$	29·08	21·81	3·852	60·30	72·70	54·53	1·541
3 & 4	43·81	$\frac{1}{51 \cdot 13}$	41·09	30·82	2·727	85·22	102·73	77·05	1·091
5	31·43	$\frac{1}{71 \cdot 27}$	57·27	42·95	1·955	118·78	143·18	107·38	·782
TRAMWAY	22·40	$\frac{1}{100}$	80·36	60·27	1·393	166·67	200·90	150·68	·557
RAILROAD	9·33	$\frac{1}{240}$	192·86	144·64	·580	400·	482·15	361·60	·232

The opposite table shows the proper inclination for a descending trade upon the foregoing roads; the effect produced by a horse upon them per day, on a level and upon the proper inclination; also the corresponding expenses per ton, per mile. The horses are reckoned to travel twelve miles loaded, and twelve empty, per diem; power and expense of horse, and weight of waggons as in page 104.

Since locomotion on railways became of such importance, nothing appears to escape investigation, nor attempts at amelioration. Anti-friction, or the diminishing of resistance is at all times essential, and in a great measure will be obtained by lubrication. An improvement in this useful auxiliary has been effected by Mr. Booth, of Liverpool, for which he obtained a patent, on the 14th of April, 1835. He has denominated it "the Patent Axle Grease, and Lubricating Fluid." These, according to the specification are chemical compounds of oil, tallow, or other grease, and water, effected by means of the admixture of soda or other alkaline substances in such proportions, that the compounds shall not be of a caustic or corrosive nature, when applied to iron or steel, but of an unctuous greasy quality, easily fusible with heat, and suitable for greasing the axle-bearings of carriage wheels, or the axles, spindles, and bearings of machinery in general. The proportions of the ingredients, and mode of compounding them, are stated to be as follow:—

"For the axletrees of carriage wheels, a solution of the common washing soda of the shops, in the proportion of half a pound of the salt, to a gallon of pure water; to one gallon of this solution, add three pounds of good clean tallow, and six pounds of palm oil. Or, instead of the mixture of palm

oil and tallow, add ten pounds of palm oil, eight pounds of firm tallow. The tallow and pa oil, or either of them, and the solution as describ must be heated together in some convenient vess to about 200 deg., or 210 deg. of Fahrenheit then the whole mass must be well stirred or mi together, and continually agitated, until the co position be cooled down to 60 deg. or 70 deg., Fahr., and have obtained the consistency of but in which state it is ready for use.

The patent lubricating fluid, for rubbing parts of machinery in general, is thus made :— one gallon of the aforesaid solution of soda water, add of rape oil, one gallon; and of tall or palm oil, one quarter of a pound. Heat th together to about 210 deg. of Fahr., and then the fluid composition be well stirred about, agitated without intermission, until cooled down 60 or 70 deg., when it will be of the consisten of cream. If it be desired thicker, a little additi of tallow or palm oil renders it so."*

* Hebert, p. 574.

CHAPTER VII.

EMBANKING.

Of attaining Elevations by Embankments and Viaducts—Their Advantages and Disadvantages—Victoria Bridge, on the Durham Junction Railway—Croft Skew-Bridge, on the Great North of England Railway—Ouseburn, and Willington Dene Viaducts, on the Newcastle-upon-Tyne and North Shields Railway—Quantity. Nature of Material, and Angle of Repose of Embankments—Batters of Slope explained—Foundations—Drainage—Imperfect method of forming Embankments—Remedy Proposed—Embanking in Layers—Mode of Expediting the Unloading of excavated Earth—Curvilinear form of Embankments—Embanking upon and adjoining Masonry—Mode of Counteracting the Pressure of Embankments, when passing over Tunnels or other Masonry—Obstructions in crossing Valleys—How avoided—Self-acting inclined Planes—Stationary Engine Planes—Endless Ropes—Inclinations for Animal Power—Equalised Inclination—Expense of unloading excavated Earth—Expansion and Contraction of Soils—Deterioration of Earth-works—Preservatives for Earthen Mounds—Slopes—Draining slopes of Mounds—Wolverton Embankment, on the London and Birmingham Railway in a state of Combustion—Cause of its becoming Ignited—Earth-waggons—Side, and Revolving-waggons. &c. &c.

On undulating surfaces, there are often very formidable summits to be attained; there is also a diversity of opinion relative to their construction; whether they are more practicably surmounted by embanking, than by adopting the viaductal form.

It is almost superflous to say that embankments are preferable, where a depository is wanted for the produce of the cuttings. They are indeed to be

preferred at any time, if the altitude is not great, even though there be a deficiency of earth, and a necessity for its being procured exclusively for their formation—provided that the space underneath is not required for some useful purpose.

But, as elevations are increased, embankments lose their superiority over viaducts in a quick ratio, and are very soon entirely superseded by the latter. This is chiefly to be attributed to the rapidity with which the sectional area of embankments is increased as they become elevated, and the enormous quantity of land they then occupy. These increasing effects are not experienced if the summit is attained by a viaduct, there being the same quantity of material contained in the arches, spandrels, approaches, and every part above the springing of the arches, whatever the altitude may be. Of course the piers, abutments, and retaining walls, below the springing will increase, even in greater ratio than their height, owing to an increase of base being requisite for an increased height; yet the additional quantity appears as nothing contrasted with the augmentation of embankments equivalent in altitude.

There have been lately erected, in the North, four splendid structures for the purpose of carrying railroads across the rivers Wear and Tees, and those of two deep ravines near Newcastle-upon-Tyne. The first one alluded to is upon the Durham Junction Railway; it is erected over the river and valley of the Wear, about six miles to the south-west of the town of Sunderland, and is distinguished by the very popular appellation of the "Victoria Bridge." Its extreme length is 930 feet; height from the bed of the river to the crown of the arch, 130 feet; and breadth across the soffit of the arch, 23 feet. The bridge contains four

semicircular arches, the span of the two centre ones being 160, and 147 feet respectively; and the span of the two adjoining arches, 100 feet each. There are also three small arches of twenty feet span, at each end of the bridge, which contribute much to the lightness of the structure. The depth of the *voissoirs* in the two large arches, is four feet six inches; and of those in the one hundred feet arches, four feet. There were used in the building of this bridge, eight hundred thousand cubic feet of stone, procured from the great Pensher quarry, the property of the Marquess of Londonderry.

Four miles to the south of Darlington, a skew-bridge is now erecting, in order to preserve the necessary elevation of the Great North of England Railway, across the river Tees, into the county of Durham. This bridge will be of considerably less magnitude than the preceding one, yet it is well deserving of attention, owing to its great obliquity; the angle of intersection with the river being equal to forty degrees. The bridge will contain four segmental arches, the versed sine or height of which will be fourteen and a half feet; and forty-six feet span at right-angles, or sixty feet on the oblique face.

There also have been two ingenious structures erected recently upon the Newcastle-upon-Tyne and North Shields Railway. The first is over the Ouseburn valley, near the former town. Its length is 910 feet, and the height of the roadway is 108 feet above the bed of the rivulet beneath. The viaduct is composed of timber, except the piers, abutments, and two arches at each end of it, which are of stone. Over the principal part of the valley extend five noble semicircular arches, three of which are 116 feet span, and the remaining two

114 feet each. There are three laminated ribs, twenty-two inches broad in each arch, composed of fourteen layers, exclusive of the capping, of three-inch deal, in lengths of from twenty to forty-six feet each, forming a sectional area of nearly six and a half feet to each rib, or nineteen and a quarter feet to each arch; which, together with the capping, make upwards of twenty sectional feet to each arch. At the west end of the viaduct there are two stone arches of 43 feet span, and at the east end, two of 36 feet span. The platform is supported across the haunches of the arches by diagonal and other braces, abutting each other in various directions, which both tend to counteract the lateral and vertical *thrusts* of the arches; and the structure altogether forms a very complete specimen of constructive carpentry.

The other erection to which we alluded is a viaduct over the Willington Dene, a few miles east of the preceding one, and upon the same railway. The length of this structure is one thousand and fifty feet, and from the surface of the stream beneath, to the under side of the railway is eighty feet. It contains seven semicircular arches, five of which are 120 feet span, and two 110 feet span each.

The construction of embankments, as well as the requisite quantity of material, will depend upon various circumstances, such as the nature of the material, and of the substratum or foundation upon which it is laid. The height is also of importance, for the angle of rest sufficient for an embankment of fifteen or twenty feet in height will be quite inadequate for one (composed of the same kind of material) of fifty feet; this is especially to be observed when forming the bottom part of clay embankments.

Embankments formed of coal, rubble stone, sand, or other materials which do not retain water in their fissures, are firmest upon the least base, particularly the first, which are much used in the mining districts, being frequently formed of a slope of one horizontal to every foot perpendicular, or an angle of forty-five degrees. But, for clay embankments, those partly composed of clay, or other absorbing materials, of the altitude of about twenty feet, a slope is requisite of one and a half to one, or an angle of 34 degrees with the horizon; and where they are required of the height of fifty feet or upwards, it is advisable to form them with a slope of two to one; in some cases even flatter.

In embanking, if the slope be stated as 1½ to 1; 2 to 1, &c.; it is understood that the latter number represents the perpendicular height. In excavating, it denotes the perpendicular depth; and both figures are always to be regarded as of the same denomination, feet, yards, &c. &c. But in rock excavations, as in masonry, the batter of slope is generally expressed by so many inches (horizontal) to each perpendicular foot or yard.

FOUNDATIONS.—When an embankment is formed upon a foundation which shrinks by its pressure, it is advisable to make it considerably broader than when on firm ground, as the mound by descending forms the base of one of far more then its apparent elevation. If this method were observed, it would tend to prevent those vast disruptions from taking place, during the time embankments are subsiding, which are chiefly attributable to the narrowness of their base.

An inferior foundation may be much improved by placing hurdles, wound with thorns or willows, underneath the mound; but, where the weight is

extreme, the inferior matter will be displaced by the gravity of the mound, until a part of it comes in contact with the more dense foundation, and the whole becomes stationary on the sides, by the superincumbent and lateral pressure.

Dry and firm foundations being at all times so desirable whereon to construct embankments, recourse must be had to drainage for their security. When the ground is of a sloping direction, or ascends from the end of the embankment (as is the case after reaching the deepest part of a valley) it is indispensably necessary to prepare sufficient drainage, to prevent the water which descends from the high lands, from accumulating at the foot of the embankment; a frequent cause of great inconvenience and expense. And when the surface slopes transversely, before any part of the embankment is deposited, there ought to be a proper drain cut on the high side to keep the foundation dry. If this be omitted, the mound invariably shrinks, by the water filtrating through underneath, frequently splitting and carrying away large portions of the earth from the low side; an injury only to be repaired by great additional outlay.

In crossing abrupt places, such as the sides of a ravine, the foundations ought to be carefully examined, such spots being often liable to outbursts of water. If indeed mounds of great magnitude are formed upon them without their being first properly drained, the pressure causes the water in escaping to intermix with the soil; and experience teaches us that, when retentive earths are once thoroughly saturated with water, *slipping* will commence, and a great length of time must elapse before their ultimate consolidation is effected. It might appear disingenuous, or we could have given

a few examples of the malformation of embankments, by way of illustration.

Embankments of great altitude, when proceeding at their full height, are attended with a constant slipping at the face, or place of delivery; owing to the subsiding of the material and the aggregation being oblique; thus causing an enormous expense to be incurred by derangements to the rails, as well as frequent stoppages to the work. In order to obviate this, and to attain some facilities subsequently explained, we would suggest that the lower part of such embankments should be formed in a succession of layers of about eight feet in depth; the thickness of the upper layers to be increased regularly, until the proper elevation is attained. Of course, the thickness of the layers would have to be somewhat modified by the firmness of the foundation and the nature of the material composing the embankment. By adopting this method the aggregation is rendered comparatively less oblique, and the larger particles are deposited and intermixed in each layer with a more equal distribution throughout the whole mass, instead of being collected together in an open and loose manner at and near the base of the embankments, as is the case when they are formed of one height. When proceeding down a declivity with a mound, embanking in layers is indispensable, in order to take the best precaution for avoiding those great disruptions which so frequently occur in some places, and are so very detrimental to the permanency of embankments.

When railways have to be expeditiously formed, the difficulty is not experienced in the cuttings, (for, by operating in layers and gullets, excavating is almost unlimited,) but at the end of the embank-

ment—a difficulty consequent on the discharge of the excavated earth. On several accounts, we most strenuously advocate the embanking in layers, as it possesses peculiar advantages for facilitating delivery, since, being formed to the full breadth of the embankment, the number of deposits are necessarily increased, especially in the lower layers, a circumstance which it must be acknowledged is a great desideratum. Many obstacles indeed are thus more easily surmounted. In crossing over tunnels or other masonry, the risk of counteracting the pressure of the embankment is diminished, and altogether it may be reasonably inferred that much expense may be avoided by its adoption.

It will be advisable at the commencement of the work to form the base to the extreme breadth of the intended embankment; and also, during its erection, to make every succeeding layer correspond with the slope underneath, and regular on the top; as pieces laid on the sides of a mound rest upon an oblique base, and invariably shrink from that part previously made, ultimately requiring a greater breadth of base than would have sufficed had they been constructed as recommended. Although the slopes are originally made with a straight batter, they subsequently become curvilinear, and the embankment rather convex on the top, being the natural shape of earthen mounds when they have subsided.

EMBANKING NEAR MASONRY.—Adjoining masonry, earthen mounds ought to be carefully deposited and *rammed* in layers of about nine inches in thickness, to prevent the action of the soil, during its subsidance, from injuring the work. Indeed, in some situations, where mounds are formed upon masonry, the whole superincumbent

mass ought to be consolidated as deposited thereon.

When the upper part of a tunnel, underneath an embankment, is erected above the adjoining surface, a quantity of the best material ought to be firmly rammed against the exposed masonry; and, if the tunnel has to sustain much pressure, there ought to be a few feet (in depth) of earth firmly punned upon the top of the tunnel, which tends greatly to prevent the subsiding of the embankment proving injurious. And when crossing over tunnels with the lower layers of an embankment, especially if the masonry is above the adjoining surface, it is absolutely necessary that a sufficiency of earth be deposited on the side of the tunnel opposite to the approaching embankment, to counteract its pressure and prevent it from displacing any of the masonry—an evil which, if not prevented, destroys the coherence of the mortar, and impairs the strength of the whole structure.

Crossing Valleys.—When crossing over a valley it sometimes happens that the necessary erections cannot be completed in sufficient time to allow the method of embanking stated in the last page being carried into effect, except by a delay of the earth-working for some time. In order to avoid this alternative, the mound is either brought forward towards the valley at its full height, or, after having descended for a certain distance, it proceeds on a lower level towards the point of stoppage, occupying, as it advances, the breadth allotted for the railway. The self-acting, or whatever kind of plane is hereafter used for conveying the earth to the bottom of the valley is therefore compelled to be formed on the surface by the side of the before-mentioned embankment, which both impedes the progress and causes additional labour at the several depositing branch-lines of railway.

It is always very desirable to have the necessary erections completed in time to avoid either delaying the earth-works or forming embankments, as described in the preceding paragraph. When this desirable object however cannot be accomplished, it will often be preferable to postpone earth-working until the above works are completed, which will greatly tend to facilitate embanking afterwards. At the same time it must be observed that the declination and length of surface between the level of cutting and embankment, and the place of obstruction will materially modify the question.

Inclined Planes.—Gravity being the most economical first mover applicable to railroads, self-acting inclined planes ought to be introduced for the removal of the excavated earth from the upper to the lower layers; a sufficient descent being provided to return the empty carriages during unfavourable weather.

When the quantity of earth to be removed is of great magnitude, and there is not the necessary preponderance of weight to work self-acting inclined planes of convenient length, stationary steam power may be made available; in which case, the planes need only have sufficient descent to cause the loaded waggons to descend, drawing a rope to return them with when empty. Should the planes be worked by endless ropes, their inclination is immaterial, unless, indeed, the distance be great, when this latter method is very objectionable, owing to the extra weight and wear of the rope, and the enormous friction caused by its winding about the wheel at the extremity of the plane; circumstances productive of great additional expense. The planes may be so constructed that after the loaded waggons have descended by gravity, the empty ones may be returned by animal

power. We may add that an inclination of one in thirty-seven would enable an ordinary horse, when exerting a tractive force of 150 lbs., to ascend it with two empty waggons of twenty hundred-weight each.

Having arrived at the foot of any of the before mentioned planes, the base and each succeeding layer, where practicable, ought to proceed with an uniform descent towards the place of delivery of 3·168 inches per chain—estimating the resistance upon the level equal to the one hundred and fiftieth part of the insistent weight, and the weight of the waggons equal to one-fourth of the gross load—so that the tractive power would be equalised and the excavated earth drawn to the place of delivery, with the same force that would return the empty carriages; thus advantageously transmitting it along the proper *descent* by at once facilitating and economising the draught.

The expense of unloading excavated earths is so fluctuating, that we have frequently experienced a difference of more than one hundred per cent. When soils are intermixed with water, it, of course, considerably retards and increases the expense of discharge; but, upon an average, about one-seventh of the price of excavating earth, or five-eighths of a penny per cubic yard, may be stated as approximating nearly to the actual average cost.

There is a constant alternate expansion and contraction in the outer part of clayey soils, occasioned by the humidity of the air, succeeded by heat and dryness, which fractures the crust of the slopes and admits the rain into the interior of the embankment. The same remark, although less forcibly, will apply to the slopes of cuttings. In order to secure embankments against such external action,

which causes great internal mischief, the slopes are often covered with a layer of soil, previously taken from off the base of the mound, and sown with grass; the soil being deposited on the slopes as lightly as possible. We consider that the method recommended in the *Gardener's Gazette* to preserve potatoes, a little modified, would be very applicable in the present instance. After explaining how they should be ridged up on the outside, similar to the slopes of an embankment, it proceeds as follows:—"Let neither a foot tread it nor a spade beat it, but leave the whole as light as the soil will admit of; but where the soil is naturally stiff, a greater thickness of it must be added, and the sides of the ridges to be left as steep as possible, and the lighter the soil is put on, the more frost will it keep out. The reason is obvious enough, for when light soil is laid on steep ridges, rain never enters deeper, perhaps, than two or three inches, it being held in a kind of solution with the fine earth by capillary attraction; or, in other words, the air in the light soil keeps the rain from sinking, consequently it runs down the sides of the ridges, and keeps the interior of the mass as dry as possible; and, of course, the frost never enters to any great depth. When the soil is trodden or otherwise made firm, the air beats out of it; every drop of rain enters, and sinks through the whole mass."

When embankments are formed, and indeed for a considerable time afterwards, the water often penetrates them from the *top*, but when it reaches parts of more firm and compact formation, being nearly prevented from insinuating itself further into the heart of the mound, it oozes out at the slopes. Hence that doughy state, so often observable at

various heights, in the slopes of embankments. When such places are first noticed, drains ought immediately to be carefully inserted into the slopes that the water may escape without intermixing with the soil. Indeed, wherever water is observed in an embankment, means cannot be adopted too soon for removing it; and the longer draining is deferred, the more disastrous will be the consequences, and greater the expense ultimately incurrred in remedying them.

When embankments are formed of clay or other retentive soils, and have partially subsided, before covering them with the permanent ballast, we would recommend a layer of plastic clay on the top, and also underneath the soil on the upper part of the slopes, to keep the high and loose part, if possible, waterproof, and to avoid the before-mentioned slipping and waste of material. Although this system would in the first instance be attended with extra expense, yet from our experience of the enormous cost in removing slips and repairing breaches made in embankments, we do not hesitate to say that it would eventually prove by far the most economical.

As an additional security, the slopes of some embankments are planted with shrubs, willows, &c., and the roots, by inserting themselves into the material, unite the particles more firmly together; yet they ought not to be allowed to grow too high, or, during the prevalence of strong winds, the upper branches will of course be violently agitated, and acting like levers in embankments will have a great tendency to weaken and injure them.

Near the coal-works the sides and tops of embankments are often covered with a layer of small coals, to keep the interior dry, which, indeed,

answers the purpose remarkably well. If not deposited too thick the coals are in no risk of becoming ignited, although we certainly have known such occurrences to take place. A rather curious incident of this kind happened at the Wolverton embankment on the London and Birmingham Railway. "There seemed to be no end to the vagaries of this embankment," observe Lecount and Roscoe; "there was a portion of alum shale in it, which contained sulphuret of iron; this becoming decomposed, spontaneous combustion ensued, and one fine morning there was the novel sight of a fifty-feet embankment on fire, sleepers and all, to the great surprise of the beholders. The inhabitants of the neighbouring villages turned out, of course, in no small amazement on the occasion; and various were the contending opinions as to the why and the wherefore. Some said—'the company were hard up for cash, and were going to melt some of the rails';—others, 'that it was a visitation of Providence, like the tower of Babel.' At last, one village Solon settled the point;—'Dang it,' said he, 'they can't make this here railway arter all, and they've set it o' fire to cheat their creditors.'"

EARTH-WAGGONS.—The chief object to be accomplished when building earth-waggons, is, that their construction shall be firm, low, and as little complicated as possible; preserving a sufficiency of height above the *soles*, (the frame upon which the fulcrum or joint for raising and lowering the waggon-body is placed) to enable the waggon to be elevated to the necessary angle for expeditiously discharging the excavated earth.

A certain number of the waggons should be built so as to quit their load at the side; which

tends greatly to facilitate the return of the empty ones; thus constructed they answer all ordinary purposes equally well with the revolving ones, which deliver their load either at the sides or end; they are less expensive, lower,—on account of the apparatus for turning revolving waggons,—and are also attended with less labour when being emptied.

Waggons of an oblong form are more steady than those of great breadth, and are not so apt to transfer the weight of the load alternately from one side of the line to the other, in preventing which a considerable tendency is gained to decrease lateral friction against the sides of the rails. An oblong waggon, however, requires additional height above the *soles*, to allow of its body being elevated to the necessary angle for discharging its load freely; both on account of its extra length, and of earth quitting a wide waggon more readily than a narrow one. In practice, therefore, it is found that a modification of both plans is preferable, namely, that of building the body of the waggons nearly square.

CHAPTER VIII.

BRIDGES AND TUNNELS.

Of Foundations in general—Tunnel Foundations—How to assist Tunnels to sustain earthen Mounds of great altitude—Securing Tunnels from the action of mounds while crossing over them—Of Stone—Its Quality—Decomposition and Disintegration of Stone—Lime—Sand—Mortar—Preparing Mortar—Grouting—Its Efficacy—Ashlar Work—Size of Blocks—How proportioned—Disposition of Blocks in a Wall—Voissoirs, or Arch-stones—Methods of dressing Stones—Rusticated Work—Block and Course Walls—Bricklaying—Imperfections of Brick—Specifying Brickwork—Disposition of Bricks in a Wall—Bond preserved—Arching—Bond in Arches—Arching with distinct Rings—Pressure against Retaining Walls of Bridges in Excavations—How avoided—Symmetry of Bridges—Bridges and Tunnels underneath Embankments—Where defective—How avoided.

Of all works requisite for a railway, there is none so much dependent on its foundation for security as that of masonry. Should any part of the foundation prove defective after the fabric is erected, it generally causes a derangement to take place throughout the whole, and should that be once effected, it is almost impossible to restore the original stability. It is manifest, therefore, that the utmost circumspection is absolutely necessary.

When preparing foundations in good tenacious soils, for the reception of masonry, it is important not to exceed the extreme sizes at the back of the intended structures; it being difficult to make the spaces as solid as the natural soil, exclusive of the e incurred in the operation.

In some instances, we have observed foundations superior to piled ones obtained by displacing the inferior material to a greater width than the intended structure, and to the full depth thereof; the vacuity being afterwards filled with rubble stone to the required height for the foundation. Indeed, wherever soils are weak, it is advisable to excavate an extra width behind the intended masonry, and fill the spaces with hard material as the erections are advanced.

On account of tunnel foundations being so liable to be filled with water, and consequently their sides so apt to be thrown down, if cut perpendicularly—and it being so essential to have them thus executed, or nearly so—when they are to be of considerable length, we would recommend them to be executed in portions, never proceeding far in advance of the masonry with the full depth. But, to expedite the cutting of a foundation, the upper parts might be executed any convenient length, depositing the produce on that side of the tunnel opposite to the approaching embankment. By operating in this manner, the sides of a foundation are sooner supported by the masonry; the size of the excavation is also comparatively diminished, which reduces the risk and expenses of pumping water and removing mud, by having only to contend with such, in that particular length in operation.

Tunnels, on account of their peculiar situations, have generally to support enormous incumbent masses of uncompact earth, therefore substantial foundations for their erection are of paramount importance. It is also essential to have them so founded that the crown of the arch shall not be higher than the surrounding surface of the ground. By thus placing them, preparing the sides of the

foundation as described in the preceding paragraph, the adjoining ground, acting in conjunction with the masonry, assists to sustain the embankment, which would otherwise have to be borne exclusively by the tunnel. Besides, when tunnels are founded in this manner, it materially tends to prevent their masonry from being injured by crossing over them with embankments, and also protects them against the lateral pressure of the earth when subsiding.

OF STONE.—In the building of bridges, tunnels, &c., the most durable materials should be employed, possessing the qualities of hardness, tenacity, and compactness, with the property of resisting the decomposing effects of water and of the atmosphere. The decay and destruction of stone in buildings, are attributable partly to the chemical changes effected by decomposition in the stone itself, and partly to the action of frost producing disunion of parts.

"Decomposition takes place, when the stone contains parts that are more or less soluble in water, or which enter into combination with the oxygen of the air or acids in water. Iron, in different states of oxydation, and in different proportions, enters into the composition of almost all stones, and is frequently an important agent in their decomposition. When stones contain pure iron, it rusts or oxydates, and expands so as to burst the parts asunder. The iron absorbing oxygen and carbonic acid from the air, the presence of moisture accelerates this kind of decomposition and it is always still further hastened by increase of temperature.

Disintegration is the separation of the parts of stones by mechanical action, the chief cause is the congelation of water in the minute pores

and fissures of stones, which bursts them open, or separates small parts, according as the structure is slaty, or irregularly granulated. The south sides of buildings, in northern climates, are most subject to fail from this cause; for the surface is often thawed and filled with wet in the sunny part of the day, and frozen again at night. This repeated operation of freezing is very injurious to the piers of bridges, and other works exposed alternately to water and frost."*

MORTAR.—It is almost superfluous to say that when uniting stones or bricks together in buildings, it is essential that the cementitious matter employed should be both tenacious and durable.

The *quantity* of powdered lime yielded from a fixed measure of well-burnt lime fluctuates considerably, although the stone may have been quarried from the same mine. The *quality* of both lime and sand is also variable; therefore no fixed ratio of the two component parts can with propriety be said to comstitute the best mortar.

Bishop Watson, we believe, proved by experiments, that upon an average, every ton of limestone produced eleven and a quarter hundred-weight of quick-lime, weighed before it was cold; but that, when exposed to the air, it increased in weight daily, at the rate of a hundred-weight per ton, for the first five or six days after it was drawn from the kiln; owing to its gradual absorption of carbonic acid.

When slaking lime, a small portion only ought to be in operation at the same time; and when wetted, immediately covered with sand, observing that the whole operation should be as rapid as

* The above, and the two quotations in the following article, (Mortar,) are extracted from Kelly's *Practical Masonry*.

possible. This method prevents the gas, or strength of the lime, from escaping, and by the sand and lime being thus mixed, it tends greatly to facilitate the labour of incorporating them together, when being reduced to the consistency of mortar.

"It is universally allowed that the hardness of mortar depends on the crystallization of the lime round the other materials which are mixed with it; thus uniting the whole mass into one solid substance. But, if a portion of the materials be clay, or any other friable substance, it must be evident that as these friable substances are not changed in one single particular, by the process of being mixed up with lime and water, the mortar, of which they form a proportion, will consequently be more or less of a friable nature, in proportion to the quantity of friable substances used in the composition of the mortar. On the other hand, if mortar be composed of lime and good sand only, as the sand is a stony substance and not in the least friable, and as the lime, by perfect crystallization, becomes likewise of a stony nature, it must follow that a mass of mortar composed of these two stony substances, will itself be a hard, solid, unfriable substance." It is therefore obvious that if the matter interposed between the crystals of the lime be composed of soil, the scrapings of roads, or any other brittle substance, the mortar will necessarily be very imperfect and friable. Consequently these substances ought to be rejected, and clean sharp sand, rather course, composed of hard, angular, quartose particles, should be introduced.

"When lime has been long kept in heaps, or untight casks, it is reduced to the state of chalk, and becomes every day less capable of being made into good mortar; because, as the goodness or durability

of the mortar depends on the crystallization of the lime, and, as experiments have proved that lime, when reduced to this chalk-like state, is always incapable of perfect crystallization, it must follow that as lime in this state never becomes crystallized, the mortar of which it forms the most indispensable part will necessarily be very imperfect; that is to say, it will never become a solid stony substance, a circumstance absolutely required in the formation of good durable mortar."

Grouting is very essential for procuring solid masonry. The lime, when quick, should be mixed with water to a proper consistency, and poured while hot upon each course, which renders solid all the interstices between the stones or bricks, and thus unites the whole mass together. It would appear that grouting was much practiced by the Romans, the efficacy of which is observable at the present time, many of their works having endured for so many centuries.

ASHLAR WORK.—As all masonry, but especially any of inferior description, gains additional strength and is better adapted for resisting pressure when the mortar has had sufficient time to be properly set, it is recommendable to have the several structures completed in due time to allow this coherence to take place.*

The size of the blocks or ashlar stones employed in building should be proportionate to the thickness

* Sometimes this desirable end cannot be accomplished. An instance of which occurred in the neighbourhood of Durham three years ago, when a stipulated quantity of work had to be executed in a limited time. The object in question, was to make a gallery for the passage through of the Durham and Sunderland Railway, underneath the junction of the Hetton and Elmore Railways; which task was entrusted to and performed by the author of the present volume. In executing the work, one hundred thousand bricks, and eighteen hundred tons of stone were used; and four thousand cubic yards of earth removed. The tunnel constructed is nearly fifty yards in length, and twenty-two feet span. The work was executed in the course of a fortnight, being the first two weeks in January, 1836; and the writer was also fortunate enough to accomplish the whole undertaking without one single accident occurring.

of the different walls wherein they have to be situate, and the blocks so disposed in the work as to cause the vertical joints of each stone to be placed as near the middle of the stones underneath it as convenient, so that by overlapping one another the whole mass may be properly connected together.

Care should be taken to avoid either short stones or those of too great length, as they prevent the regular connection of others. No stone ought to be shorter than one and a half, nor yet much longer than three times its thickness. The former often causes it to be laid upon and under two stretchers; the latter, forming those stretchers, are compelled to be laid across it to make face-bond with the two adjoining stones—thus forming no face or longitudinal bond with the short stone. Two stretchers thus situated are apt to be broken by their additional length, and also from the difficulty of giving the short stone its due proportion of pressure. Voissoirs, or arch-stones, thus placed, are particularly objectionable, and should on no pretence be admitted into arches having much pressure to sustain.

Particular attention is also necessary whilst preparing the stones, in avoiding any concavity or twisting in their beds and joints, in order to form the surfaces as regular as possible. When stones are of great breadth it is desirable either to work extra draughts, that is, narrow strips coinciding with a straight-edge or rule used for that purpose, along and across their beds; or to work draughts diagonally across them. By preparing the stones in this manner their beds may be rendered straight and level, and their *setting* accomplished without the aid of *pinnings;* thus securing to each bed an uniform bearance for its whole area, which also

tends greatly to prevent the stone from *flushing*—becoming fractured at and near the joints. Flushing, however, is often partially avoided by rusticating the joints; embracing at the same time an improvement in the appearance of the masonry.

Block-and-course work is a species of serviceable masonry much used in the building of occupation bridges, small tunnels, walls, &c. It is externally composed of stone, in courses of from five to ten inches in thickness; eight to twenty inches in breadth; and in lengths of from eight to fifteen or twenty-four inches. At intervals these stones are connected with the interior of the wall by bond-stones similar in thickness, containing from eight to twelve superficial feet each, according to the breadth of the wall, and constituting about one-sixth of the whole cubic content. The interior and back part are composed of common rubble, which should be well connected together, and also to the stones in front; but no course or layer should ever exceed fifteen inches in height, until the whole *breadth* of that part of the wall is completed.

BRICKLAYING.—This art is of the greatest antiquity, appearing indeed coeval with the existence of the human race. It is at least an antedeluvian invention, as we are distinctly told that bricks were employed in building the tower of Babel; somewhere about the year A. M. 1758.*

* "And they said one to another, go to, let us make bricks and *burn* them thoroughly. And they had brick for stone, and slime had they for mortar." Making bricks was also one of the laborious indignities imposed on the Israelites during their servitude in Egypt, according to the following passage; —"Ye shall no more give the people straw to make brick, as heretofore; let them go and gather straw for themselves. And the tale of the bricks which they did make heretofore ye shall lay upon them; ye shall not diminish ought thereof." Now, it is doubtful whether the bricks in this process were actually exposed to the action of fire, as may appear to be implied by the literal text, or merely dried in the sun; the latter is however the most probable, because, even at the present time, sun-dried bricks are extensively used throughout the East.

Bricks may be considered as a kind of factitious stone. They are composed of argillaceous or clayey earths, well tempered during the winter months, and afterwards formed in moulds, and dried in the sun, previous to being burnt. Bricks are very generally employed in public works, and if composed of dense adhesive particles, and properly burnt, are very durable.

Bricks are subject to many imperfections, such as vacuities caused by mixing the clay with small coal and partially burnt cinders which have escaped through the grates; these, being combustible, cause perforations in the bricks when in the act of burning. The existence of limestone in bricks is also very prejudicial, but may easily be discovered by immersing them in water, the admixture to any injurious extent, being then rendered very obvious.

The surfaces of bricks are very subject to be covered with loose earthy particles, which prevent the mortar from adhering; but in order to free them from such impurities they should either be put in water, or have quantities of it thrown upon them prior to their being used. Additional strength is thus obtained, for, by cleansing the bricks, the mortar adheres firmly, and unites the whole together, forming one solid mass throughout. In arching, wetting the bricks is not only essential, but also tends greatly to facilitate their laying, especially in the central part of arches, where the courses* become nearly vertical.

Brickwork should be made of so many bricks in breadth, and not specified in feet. The back of a battering wall ought to be kept in parallel planes with its face, reducing it regularly by scarcements

* The whole of the bricks in a layer of the thickness of one brick constitute a *course* of brickwork. The same will apply to a wall, whether the bricks are laid parallel with the horizon or otherwise.

at the back; and walls tapering longitudinally ought to have their breadth reduced in the same manner, in order to prevent refuse pieces of bricks being inserted in every course.

A great defect in the laying of bricks is the not mortaring the joints of the outside bricks to their full breadth, and the headers to their full length; an omission which allows the wet and frost to penetrate into the interior of the wall; producing those evil consequences so often observable in the interior of dwelling-houses.

The disposition of bricks in a wall ought to be so regulated that the extremities of no two laying contiguous to each other shall coincide, but, that the extremities of each brick shall stretch half way along the sides of those adjoining to it; and that all the bricks in the same course, or layer, shall lay in the same direction. The best method of securing this regular connection exists in what is termed *English bond*, which consists of one course of stretchers and one of headers alternately; the *stretchers* being the bricks which have their lengths disposed in the wall longitudinally, and the *headers* those having their lengths laid in the thickness of the wall. Every alternate outside header, on both sides of the wall, being only half the length of a brick, in order to connect the external heading bricks with those in the interior of the same course; thus rendering the half bricks available in producing bond. Adjoining the head of each quoin-brick, and diagonally through the courses to the interior angles of each returning or cross-wall, pieces, one quarter of the length of a brick, are necessary to prevent the occurrence of what are termed straight joints on the face of the wall, and also to preserve the continuity of bond at those intersections.

It is almost superfluous to say that bricks forming the frustrum of a wedge—usually termed radiating bricks—are the best adapted for constructing arches; common bricks, having their beds in parallel planes, cannot strictly be considered as constituting any part of arches. But, there being generally a great discrepancy in the thickness of common bricks, by carefully selecting them, and procuring bricks from different kilns, we obtain them of various thicknesses; hence by laying the thin bricks at the intrados, the thicker ones behind, and those of the *greatest* thickness at the extrados, we obtain—without additional mortar—arches of great strength and durability. This is the method commonly resorted to, in practice, and which is found to answer the purpose even under embankments of great altitude.

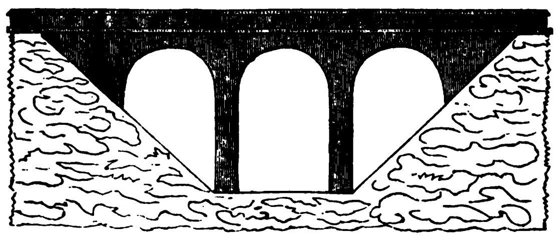
But, when arches are of small diameter, the above method becomes inapplicable; and if radiating bricks are not used, the arches are either composed of distinct rings of brick-work, or extra rows of bricks are introduced into the interior and back part of the arches, and bonded together, at intervals, where any two rings of brickwork happen to coincide.

In arching with *distinct* rings of brick-work, it is indispensably necessary to use every precaution, such as avoiding extra thickness of mortar, irregular keying of arches, &c., in order to give to each distinct ring its due proportion of pressure, so that they shall act in unison with each other; and, comparatively speaking, the component parts thereof constitute only *one* ring.

When connecting two rings together, as adverted to in a former paragraph—especially should many courses of bricks intervene between the places where they are bonded—we would recommend, in

general, the bonding them together with two single rows of headers, laid immediately upon each other; the upper headers crossing those underneath half the breadth of a brick, longitudinally; we urge this, conceiving that the thickness of one brick is often inadequate to bond two rings securely; for, when the arch becomes loaded, a trifling deviation of form takes place, which has a great tendency to snap in two the bond bricks at those places.

The pressure against the retaining walls of bridges erected in deep excavations, is immense, often altering their position, fracturing, and ultimately rendering the structures very insecure. In such situations it will be prudent to dispense with the building of retaining walls, and erect the bridges with piers and arches, as shown in the subjoined elevation; which not only greatly re-

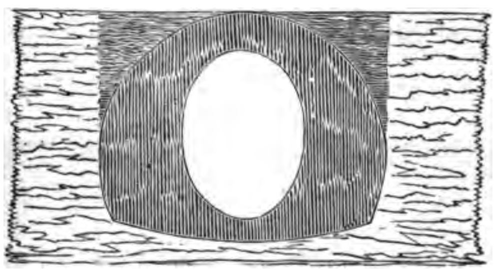


duces the pressure against the before-mentioned walls, but renders the structures superior in appearance, and is accomplished also without incurring any additional expenditure.

In erecting such bridges, it is a good rule to observe that the height of the arches must not exceed that of the piers: where the latter are of great elevation, semicircular arches *may* be intro-

duced to advantage; but where bridges are erected in shallow cuttings, the lower kind of arches are preferable; indeed, piers of any elevation may consistently be surmounted with the latter.

When a communication is required underneath an embankment of great altitude, it is desirable to erect the arch nearly to the extreme breadth of the embankment, to avoid a necessity for retaining or wing walls; these being very apt to be fractured by the lateral pressure of the mound when subsiding, and not unfrequently thrown over when a disruption takes place in the mound.



In circular tunnels, we have frequently observed the masonry of the upper part of the arches seriously injured by the superincumbent earth, especially underneath the centre of embankments; a circumstance obviously caused by the pressure on the arches being unequal. Serious defects arise also from inverts having too little curvature; indeed, so much so, that in some cases, inverts have risen up in the middle, which allowed the bottom part of the side walls of the tunnels to be forced in. We have been thus induced to believe

that by making those erections of an oval or egg-shape, similar to that represented in the preceding transverse section, the unequal pressure on the *quarters* before alluded to, and on the sides of the tunnels, would be materially diminished if not entirely avoided; and perhaps cause the resultant of the different pressures to become nearly concentrical. We have therefore adopted this plan underneath embankments, some of which were upwards of sixty feet in altitude, and the results were in accordance with our anticipations.

CHAPTER IX.

FENCING.

Setting Fences—Proper Season for planting Quicks—Methods of Planting and Cleansing—Proper Age for planting—Expense of Quicks—Favourable Soils—How prepared—Plants require Attention and Protection—Should be Manured—Pruning Hedges—Form—Cutting and Warping—Willow and other Hedges—Planting Quicks—Evil Effects of injudicious Pruning—Fence Railing—Impropriety of using too light Fence Railing—Expense—Stone Fences—Dry-walls—Cause of Failure—How avoided—Coping of Fence Walls, &c.

Good close hedges are very essential adjuncts to a railway, and if properly planted and in a thriving condition, nothing more decidedly improves its finished appearance.

When a line of railway has been staked out, we would recommend that only the fence railing should be erected, until the excavations and embankments are completed; as a young hedge is so apt to be trodden down, and the quicksets destroyed, whilst such works are in operation.

Advantage ought to be taken during open seasons, say from October to February, or until the middle of March, to plant the quicks before the sap rises; and it should be observed that young hedges ought always to be kept clean; no weeds being suffered to grow amongst them, especially for the first three or four years.

Along the tops of excavations the quicks should be set near the surface, having a good mound above them to afford moisture to their roots; but at the foot of embankments they ought to be a little elevated, as a preventive of excessive damp during winter. They ought also to be placed on the *outside* of the mound, in order that the latter may form a barrier to secure the plants from occasional slippings of the embankment. Quicks, three years transplanted are decidedly the best. They certainly are more costly in the first instance than younger ones; but eventually become by far the cheapest, and also form a hedge much sooner and stronger. We have frequently noticed the speedy growth of such quicks when judiciously planted and carefully preserved. At present they are selling at the rate of fifteen shillings per thousand.

The subjoined particulars relative to hedges are extracted from a work entitled *Useful and Ornamental Planting*, published (1832) under the superintendence of the Society for the diffusion of useful knowledge. "There are several kinds of *quick* fences, which differ merely in the mode of planting the thorns (*Cratægus oxycanthus.*) The white thorn is a plant much checked in growth by every other, whether herbaceous weed or shrub, that mingles with it in the soil. It delights in a strong loam, on poor sands, or damp clay; and requires great attention in the preparation of the soil, in the selection of the plants, and in the mode of planting. It must be carefully protected from cattle and rabbits, which, by nipping off the tender first shoots of the spring, seriously injure its growth, and defeat the intention of raising an effective fence at the least cost, and in the shortest space of time.

On poor sandy soils, the depth of earth for the reception of the plants should be made as great as possible, and they should be placed on the top of the bank. Manure of rotten leaves, compost of marl or clay, and dung, ashes, or any substance that will enrich the line of planting, should be dug in if possible for the encouragement of the roots of the young quick. Where the soil is damp and clayey, planting the thorns on the face of the bank is the best practice. The ground should be perfectly clean, or the cost of weeding it afterwards will be considerable, and the fence will make little progress, if it do not fail altogether.

The cost of the manure above alluded to will be amply repaid by the more rapid growth of the quick, saving much of the expense of weeding, and of filling up blanks and gaps in the hedge, which always accompany the rearing of this kind of fence on poor or badly prepared ungenial land. The size of the plants deserves particular attention, for by planting strong three-year-old transplanted thorns, the success of the fence is secured, and the distance of time for its completion shortened by three years.

In the management of the hedges when planted, weeding is most essential, for if coarse grass or rampant weeds are suffered to mingle with the lower branches and foliage of the quick, the injury is very considerable. The top of the hedge should be kept level from the first cutting, until the plants have attained to the desired height. The sides of the hedge ought to be kept also of an even surface; by shortening the side branches every year to within an inch, more or less, of the preceding year's wood, the bottom of the hedge is maintained equally thick and impenetrable with the upper

portion. The most generally approved form of a hedge is that of the *hog's mane;* however, if the soil has been properly prepared, the plants selected of the largest size, and the keeping clear of weeds, and most judicious mode of pruning persevered in, the hedge will flourish in every shape.

By keeping the top of a hedge level, it is not meant that all the plants should be shortened in the leading shoot of the stem, but only those which overtop their thin neighbours. If this be properly attended to, the evil effects which follow the practice of shortening without exception the leading shoots of every plant of the hedge will be avoided, as well as those which occur when the upright growth of any plant is left uncontrolled until it reach to the desired height.

Where a hedge has been neglected, is overgrown and irregular, the best mode is to cut it down level with the soil, and then to dig the earth about the stumps, inserting plants of strong quick in the gaps where they occur. It may happen that the fence cannot be dispensed with, for the time the young shoots from the old roots require to renew the fence. In this case, the mode of cutting a fourth part of the stems to the desired height, and another fourth part a few inches from the ground, and warping the remainder with these, is found a useful practice.

Besides the white thorn or quick, and the furze (*Ulex Europæus*), there are many other shrubs which may be planted under certain circumstances with effect as fences. In exposed cold soils, the Huntingdon willow, beech, birch, and alder, may be used with advantage." It might be added that we have sometimes observed in damp situations along the foot of railway embankments common willows planted with advantage; and that they

throve wonderfully and soon formed a good fence.

The subjoined extracts are selected from *British Husbandry*, a useful work published in 1837, by the same excellent institution. "In the month of October, it has been before observed, the season for planting will commence, and this work may be carried forward during the winter, or until the middle of March.—Mark out the intended line of the ditch, nine inches apart from the line where the quick-wood is intended to shoot up. Take a spit of earth nine inches wide and three inches deep from out of the intended ditch, and invert it upon this space—lay it neat and level, cut off the tops of the thorns two inches above the root, and, if needful, shorten the tap-root. Place the plants, so cut, four inches apart between plant and plant, in such a manner that the tops may appear exactly above this 'cooping'; cover the roots first with another spit of earth from the surface of the intended ditch, and then sufficiently with next best soil from the same place; but do not overload the roots with earth."

"A hedge planted in this manner requires, in order to render it a fence in the shortest time, a little judicious pruning. It should be considered that the main strength of a hedge consists in the *unyielding stoutness of the principal stems;* and to have these of the requisite strength, they should only be moderately pruned on each side, cutting out the strongest branches, which act as rivals to the stem, but *never topped* until they have acquired a diametric bulk of one inch at the height of three and a half feet from the ground. When this strength of stems is obtained, the hedge is complete as a fence against all kinds of cattle which are not high leapers, and will so continue for many years, with

no other labour than what may be annually given by a keen trimming-hook, or by shears, to keep it from uselessly spreading.

Many fine young hedges are ruined by being too frequently headed down at different heights in their youth. It should be remembered that every individual thorn in a hedge is like a single tree planted on a lawn, both of which are wished to rise into full strength and stature as soon as possible; but this result can surely not be obtained by repeatedly cutting off the head of either one or the other. When a sufficient number of stems can be once made to rise from the bottom of the quick either in the first or second year, the leaders should never be cropped till they have gained the requisite strength; for by so doing, a thick mass of spray is produced, which, to the eye, appears a barrier, and, for a short time a fence against sheep; but not against a mounted sportsman, who will trample it down, or against heavy cattle, which in browsing, press through it. Besides, by heading down before the stems are sufficiently strong, the hedge becomes top-heavy from the abundance of spray, which shades, and eventually kills that below, rendering the stems naked at bottom; through which pigs, or lambs, or Welsh sheep soon make thoroughfares."

RAILING.—A very erroneous plan of fencing consists of using too light scantling for the posts and railing, so that they are frequently destroyed by cattle and otherwise, and require continual repairs; indeed, not unfrequently, to be replaced altogether, before the hedges can form a sufficient fence. We have known many thousand rods of fence-railing executed in this county at the rate of three shillings and nine pence per rod of *seven* yards, including the expense of all materials, leading and labour:

the holes for the posts being dug two feet deep in the ground; the posts sawn, holed, and set with three rails in height. In our opinion it would be far more advisable to pay an additional price in the first instance, and have *stronger* fences set, which would avoid many expenses hereafter, and well repay for the additional price incurred.

WALLS.—Stone walls are extensively used in some districts as a mode of fencing. Sometimes they are built with mortar, but more commonly without it; when they are termed *dry-walls*. The former kind is certainly always preferable, providing that lime be attainable at a reasonable expense. Of both kinds, however, we must observe that the stones ought to be well connected together by bond-stones the breadth of the wall. When speaking on this subject it is worth remarking that *ties* are often very injudiciously introduced; the wall being carried up for a certain height without any *throughs*, and then a profusion of them occurring, frequently laid so near each other that no body of wall can be inserted between them: hence the frequency of failure in the walls at such places. Now, were the *throughs* properly distributed throughout the wall, no more labour would be requisite than in the preceding mode; but the wall would become considerably stronger and more durable. It might be added that this mode of *throughing* applies with equal force to any kind of masonry.

The *coping* of fence-walls is also very important; the simplest and best kind being that composed of the flattest stones placed edgewise. These should always be set in good *mortar*; overhanging the wall, and be properly wedged together by chips of stone, until they become compact and individually immovable; when they afford very effective protection to the walls beneath.

CHAPTER X.

PERMANENT WAYLAYING.

Utility of Malleable and Cast-iron rails contrasted—Birkenshaw's Patent Wrought-iron rails—Comparative Weights required for each kind of Rail—Malleable iron susceptible of great change of form without diminishing its cohesive power—Property of being extensible or malleable prevents exfoliation—Resists separation from its adjoining particles with nearly equal forces—Cast-iron hardest and toughest at the exterior—Cause—Oxydating effects of each kind of Rails considered—Comparative wear of Malleable and Cast-iron both wheels and rails, from actual practice—Permanent Roads—Ballasting—Drainage—Depth of Ballast—Materials for Ballasting—Consolidating Ballast—Packing blocks and sleepers—Drainage of ballast—Stone blocks—Quality of stone—Chairing blocks—Waste of stone by Percussion—How avoided—Fixing blocks at right-angles—Obliquely—Advantages and Disadvantages of each method—System proposed, combining the Advantages of each—Of roads laid upon Transverse Wooden Sleepers—Their utility—Laying Curved Roads—Grooved rails for crossing roads upon a Level—Description of the mode of fixing the Chairs and Rails upon the Manchester and Liverpool railway—Mr. Losh's—Parallel malleable iron rails, and mode of Fixing—Improved Chairs—Dimensions and weight—How fixed to the Rails—Fastenings by Pins—Keys—Clasps, &c.—Continuous timber bearings—Originally used in America—Used upon the Great Western Railway—Newcastle-upon-Tyne and North Shields Railway—Utility of Longitudinal Bearers—Materials, &c.—Method of Fixing—How Connected and Secured—Patent Felt introduced—Continuous Rails described—Their Weight, &c.—Borrodail's "Patent Felt."

After the old wooden railways had been superseded by cast-iron ones, another important improvement took place, namely, the use of malleable iron rails. At the introduction of the latter, however, a great prejudice existed against them; upon the grounds that from their softness and fibrous texture, they would be liable to exfoliate, and consequently wear

fast away &c. As the subject is of considerable importance we have selected the opinions of different gentlemen conversant with such matters.

In Mr. Chapman's report relative to a communication between Newcastle-upon-Tyne and Carlisle, the following passage favourable to cast-iron occurs:—"The railway may either be formed of cast-iron or malleable iron. The latter may be somewhat less expensive, and has been found eligible in rolley-ways below ground, in which the weight on each wheel is not considerable: but, above ground, with heavy waggons, their utility, or rather their duration, is not likely to be so great as rails of cast-iron of due strength; because with heavy carriages, and case-hardened wheels, (which are much in use except for locomotive engines, as it would diminish their adhesion to the way), the following effect is produced from the softness of malleable iron, viz., the rails formed of it being drawn out between rollers, and consequently fibrous, the great wheels, rolling on those ways, expand their upper surface, and at length causes it to separate in thin laminæ. The injury from oxydation is comparatively small."

This report, as might naturally be expected, drew a reply from one of the advocates of malleable iron, and accordingly we find Mr. Longridge, a proprietor of the Bedlington Iron-works, warmly defending its utility. He also produced the following letter from Mr. Thompson, Lord Carlisle's agent at Tindale Fell, Cumberland, where malleable iron rails had been in use for sixteen years:— "The whole of the wrought-iron which has been used from twelve to sixteen years, appears to be very little worse. The cast-iron is certainly much worse, and subject to considerable breakage, al-

though the rails are about double the weight of the malleable iron rails. The waggons used to carry near a Newcastle chaldron, viz. 53 cwt."—*Newcastle Courant, December* 18, 1824.

Subjoined is the elaborate report of Mr. Stephenson, the gentleman who successfully completed that wonderful enterprise, the Liverpool and Manchester Railway. The report will well repay attentive perusal. It showed very clearly at the time it was written, the superiority of malleable iron, which has indeed been fully corroborated since by practical experience.

"The great object in the construction of a railroad, is that the materials shall be such as to allow the greatest quantity of work to be done at the least possible expenditure; and that the materials also be of the most durable nature. In my opinion," continues Mr. Stephenson, "Birkenshaw's patent wrought-iron rail possesses these advantages in a higher degree than any other. It is evident that such rails can at present be made cheaper than those that are cast, as the former require to be only half the weight of the latter, to afford the same security to the carriages passing over them, while the price of the one material is by no means double that of the other. Wrought-iron rails, of the same expense, admit of a greater variety in the performance of the work, and employment of the power upon them, as the speed of the carriages may be increased to a very high velocity without any risk of breaking the rails; their toughness rendering them less liable to fracture from an impulsive force, or a sudden jerk. To have the same advantages in this respect, the cast-iron rails would require to be of enormous weight, increasing, of course, the original cost.

From their construction, the malleable iron rails are much more easily kept in order. One bar is made long enough to extend over several blocks; hence there are fewer joints, or joinings, and the blocks and pedestals assist in keeping each other in their proper places.

On this account, also, carriages will pass along such rails more smoothly than they can do on those that are of cast-iron.

The malleable iron rails are more constant and regular in their decay, by the contact and pressure of the wheel; but they will, on the whole, last longer than cast-iron rails. It has been said by some engineers, that the wrought-iron exfoliate, or separate, in their laminæ, on that part which is exposed to the pressure of the wheel. This I pointedly deny, as I have closely examined rails which have been in use for many years, with a heavy tonnage passing along them, and on no part are such exfoliations to be seen. Pressure alone will be more destructive to the cohesive texture of cast-iron than to that of wrought-iron. The true elasticity of cast-iron is greater than that of malleable iron; *i. e.*, the former can, by a distending power, be drawn through a greater space, without permanent alteration of the form; but it admits of very little change of form without producing total fracture. Malleable iron, however, is susceptible of a very great change of form, without diminution of its cohesive power; the difference is yet more remarkable, when the two substances are exposed to pressure, for a force which, in consequence of its crystalline texture, would crumble down the cast-iron, would merely extend or flatten the other, and thus increase its power to resist the pressure. We may say, then, that the property of being extensi-

ble, or malleable, destroys the possibility of exfoliation as long as the substance remains unchanged by chemical agency. A remarkable difference, as to uniformity of condition or texture in the two bodies, produces a corresponding want of uniformity in the effects of the rubbing or friction of the wheel. All the particles of malleable iron, whether internal or superficial, resist separation from the adjoining particles with nearly equal forces. Cast-iron, however, as is the case with other bodies of similar formation, is both harder and tougher in the exterior part of a bar, than it is in the interior. This, doubtless, arises from the more rapid cooling of the exterior. The consequence is, that when the upper surface of a cast-iron rail is ground away by the friction of the wheel, the decay becomes very rapid.

The effects of the atmosphere in the two cases are not so different as to be of much moment. On no malleable iron railway has oxydization or rusting taken place to any important extent.

I am inclined to think that this effect is prevented on the bearing surfaces of much used railways, by the pressure upon them. To account for their extraordinary freedom from rust, it is almost necessary to suppose, that some diminution takes place in the chemical affinity of the iron for the oxygen or carbonic acid. The continual smoothness in which they are kept, by the contact of the wheels, has the usual effect of polish, in presenting to the destroying influence a smaller surface to act upon. The black oxyde, or crust, which always remains upon rolled iron, appears to act as a defence against the oxydizing power of the atmosphere, or water. This is the reason why the rail does not rust on its sides."

A great difference in the tendency to rust has been remarked between wrought-iron rails when either standing upright or laid carelessly upon the ground, and bars of the same material fixed, and subjected to the continual motion of carriages; the former continually throwing off scales of oxydated iron, while the latter is scarcely at all affected.

Since the date of Mr. Stephenson's Report (now a very considerable period) the nature of both kinds of material has been to a great extent developed, and the result is decidedly favourable to the adoption of malleable iron. It has also been clearly demonstrated that the wear is greatest upon cast-iron both by the action of locomotive engine-wheels (made of the two kinds of material;) and by minutely weighing each kind of rails, after being subject to certain weights passing along them for a specified time.

We shall now proceed to show from unquestionable sources the accuracy of what has just been stated. Upon the Killingworth Railway, common cast-iron wheels were originally used for the locomotive engines, but were at length superseded by wrought-iron ones. The following extract* shows clearly the relative wear of the two kinds of material. "The average wear of the cast-iron wheels was above half an inch in nine months; and with the wrought-iron tire, the wear of one pair of wheels has been one-fourth of an inch in three years, and with three other engines, one-eighth of an inch in twelve months; making the wear at least as five to one in favour of wrought-iron. The actual wear of the rails will not be to the same extent as this, as the engine-wheels sometimes slip

* *Treatise on Railroads* by Mr. Nicholas Wood, in which will be found a mass of useful information on the subject of railways and carriages; likewise numerous accounts of original experiments relative to both.

round, or slide upon the rails in bad weather. The wear of the wheels of the common carriages will not be so much, for the same reasons; but although it should be observed, that from this we ought not to deduce the actual duration of wrought-iron rails, as, their surfaces being narrower than the wheels, the wear will be, perhaps, more than proportionably greater; yet the relative wear should, however, remain the same."

Subjoined is the comparative duration, or loss of weight of wrought and cast-iron rails, upon the Stockton and Darlington Railway; the particulars being given as obtained under the minute inspection of the engineer, Mr. Story.

Malleable Iron Rails, fifteen feet long, over which locomotive engines pass, weighing from eight to eleven tons: waggons and their loads, four tons each.

86,000 tons passed over in a year, exclusive of engine and waggons.

Weight of rail, 1 cwt. 24½ lbs.
Loss of weight in 12 months, 8 oz.

Cast-iron Rails, four feet long, over which waggons only pass, weighing four tons each, when loaded.

86,000 tons passed over in a year, exclusive of waggons.

Weight of rail, 63 lbs.
Loss of weight in 12 months, 8 oz.

The loss of weight in malleable-iron rails, when waggons *only* passed over, was, in the same period, eight ounces for fifteen feet length—the same quantity of goods, 86,000 tons.

It would appear that the trifling waste of wrought-iron bars previously stated, may be attributed to a peculiar circumstance. "The causes of the preservation of malleable iron bars, exposed to the weather from rust, and their slow wear, may be readily supposed to be the constant friction to which they are subjected by the traffic, and to the condensation of the upper surface of the metal by the heavy weights rolled over it, which produces a hard compact coat, like that produced by cold-hammering steel and copper plates."—*Hebert.*

Ballasting.—Experience has proved that by judicious drainage and the use of proper materials* a sound bearance for a permanent road can be accomplished upon almost any kind of foundation. We allude to the Manchester and Liverpool Railway being carried over Chat Moss; sometimes running above, sometimes below, and sometimes on a level with the moss; an achievement which, prior to that great work, was generally considered wholly impossible.

We presume that it is almost superfluous to notice the expediency of allowing embankments to subside, before coating them with ballast for the permanent road: yet it too often happens that the ballasting is commenced immediately after their formation; the railway, from impatience or necessity, having to be opened out to the public within a brief given time.

The formation-level of a road having been adjusted, the next operation is the covering it with a layer of broken stone or other open substance, upon which is laid a coating of small coals, ashes, gravel, or whatever kind of ballasting-material the

* A great part of the Chat Moss embankment was formed with *moss* after it had been first properly drained. Hurdles, wound with heath, were also used in many parts of it.

district will afford. The layer should be about twenty inches in depth—exclusive of the broken-stone foundation—that is to say, deposited six or eight inches deep below the blocks, and the remainder distributed between and upon them; although in some situations, damp or spongy for instance, an additional thickness of ballast will be necessary. Such places, however, should never be ballasted until they have been first properly drained.

Small coals, or ashes, are decidedly the best materials for ballasting; they considerably diminish the expense of maintaining a railway, owing to their being so expeditiously packed solid underneath the blocks, the comparative ease with which they are displaced to re-adjust the latter, and their peculiar permanency when once properly consolidated. The trifling number of workmen employed upon roads laid with such materials fully bear out these assertions.

Where good ballast is scarce, the choicest part of it ought to be selected and deposited in continuous lines, immediately *beneath* the blocks; the remaining part of the roadway being composed of the inferior material. If small coals, or ashes, can be procured to form these lines, we earnestly recommend their adoption, for the reasons already assigned. It is almost superfluous to say that, if *animal* power is intended to be employed, hard materials are indispensable for the middle part of each track.

It is advisable that the ballast and any fresh material which may have been added to an embankment, should be properly rammed or rolled and made as firm as possible, previous to, and also during the time of fixing the blocks; on account of their consolidation being made more perfect and the work accomplished with less expense, than when the roads

have subsequently to be re-adjusted. Indeed, when we consider the immense pressure exerted upon the stone, it is obvious that it cannot bear upon too firm a foundation.

Rubble Drains introduced beneath the ballasting are very essential for keeping the foundation of roads dry and firm: one drain ought to be laid longitudinally along the middle of the roadway, having others (*one-half* of the breadth of the roadway in length) intersecting it at *alternate* right-angles, at intervals of about five feet each; and the former kept a little higher than the latter, to give them a descent for discharging the water more freely.

The side-drainage of excavations ought also to be frequently cleansed of all extraneous matter—particularly if their length be considerable, or of slight declination—and kept at least six inches *below* the foundation of the ballasting.

Stone Blocks. On account of the latent situation of stone, where used as railway blocks, it is much less subject to atmospherical changes than in buildings; nevertheless, it is under the immediate influence of a more rapidly destructive agent, owing to the immense shocks which it has to sustain from the ponderous weight of engines and carriages rolling over it. The stone ought therefore to be composed of a *hard*, granulated, uniform texture, to prevent either breakage, or the railway chairs inserting themselves *beneath* the upper surface of the stone. Laminated stone too, although hard, is objectionable—if its layers do not firmly cohere together—on account of its splitting horizontally when fixing or re-adjusting the blocks; especially during the latter operation.

When chairing blocks care should be taken to have the middle part of their upper surfaces ren-

dered perfectly *level*, to allow the chairs to stand firmly upon them. This is too often disregarded, but it is obvious that when the chair does not rest upon the *whole* of the under surface, its equal bearing is destroyed; a circumstance very injurious to the blocks; the waste of the stone being increased by percussion.

Where stone of a soft quality only is attainable for making blocks, a piece of *felt* might very judiciously be introduced between each chair and block, to prevent, or at least lessen, the destruction of the latter by the above cause. We have recently examined several old blocks, where the base of the chairs had been imbedded into the stone to a depth of two inches and upwards; which had, in fact, occasioned a frequent necessity for the upper surfaces of the blocks to be lowered, in order to replace the rails in the chairs.

Setting Blocks. When fixing blocks at right-angles with a line of railway, it is extremely difficult to consolidate the ballast underneath them. The distance between the centre of each block is usually one yard, and where they are two feet square, it is obvious that the stones are one foot asunder. This prevents the foundation upon which they immediately rest from being properly rammed underneath. To obviate which, recourse of late has been had to the placing blocks diagonally instead of square, which causes their opposite corners to stretch along the line of road; thus rendering every side and underneath them available; besides, the *packing* of the blocks is infinitely superior to those set at right-angles; both when being fixed, and when being afterwards rectified.

But, where cast-iron rails are used, the distance between the blocks becomes greater than that

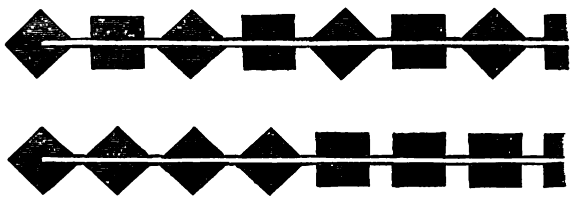
stated in the preceding paragraph, on account of the rails being generally in four feet lengths; which, of course, causes the centre of each block to be also four feet distant from the next; and if the blocks are two feet square, they are two feet asunder: hence a sufficiency of space is afforded for consolidation.

When a load is passing along a railway its weight is alternately transferred from one side of the road to the other, as has been previously stated. One line of rails is thus alternately acting as the fulcrum of the weight, and causing the greatest force to be exerted at the extremities of the blocks immediately underneath the weight. Now, by setting blocks obliquely, there is, comparatively, an additional breadth of bearing surface obtained; but their extremities, where the action is greatest, are reduced to mere points, as exhibited by the left side of the lower part of the opposite diagram. The greatest breadth of each stone is thus deposited underneath the rails, and consequently underneath the fulcrum, where it is subject to the least action and pressure; while every block laid at right-angles presents *two feet* of effective bearing surface at each extremity, to sustain both action and pressure.

When stone blocks are laid upon a foundation which does not shrink by the pressure exerted upon it, the defectiveness of the oblique method is considerably modified, and of course it becomes less objectionable; but of the *two* methods, we should generally give the preference to that in which right-angled blocks are employed.

In laying permanent roads with *stone*, we advise a *combination* of the two preceding modes of fixing blocks, in order to avoid the defectiveness at the

extremities of the oblique ones, and also to obtain the facility they afford when being packed, conjunctively with the preservation of as much bearing surface as possible at the extremities of those in the right-angled method. We suggest, therefore, that the stones should be laid alternately square and



oblique, as represented by the upper line of blocks in the above engraving, which system of *fixing stone blocks* permanently, would in our opinion, be infinitely superior to any one hitherto introduced.

A very unpleasant sensation is frequently experienced in carriages when passing along embankments where the rails are fixed upon wooden *transverse* sleepers (bearers): this does not arise from the constructive principle of the road as imagined by some persons, but from the sleepers being too slender and having consequently too much springing at their extremities. The undulating and oscillating motions thus produced might easily be avoided by using sleepers of sufficient scantling.

When it is intended to lay a road with stone blocks, it is always best to defer their laying upon embankments and use timber transverse sleepers until the latter have in a great measure subsided: even then, it is better to retain one wooden

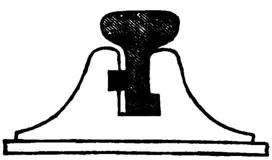
sleeper for each pair of joint-chairs to bear upon, in order to preserve the parallelism of the rails.

CURVED ROADS.—In the making of railways curves are almost unavoidable, and when the degree of curvature is considerable the friction of the carriages becomes enormous, by the wheels of the latter pressing against the sides of the rails. To obviate this, the rails ought to be of a segmental form (horizontally) and these in the outer curve of each track a little elevated along the whole range of the curve, in order to counteract by gravitation the tendency of the carriages to proceed in a straight direction. In some places we observe rails of greater strength introduced where the roads are much curved, and very judiciously; for it is obvious that additional lateral strength is requisite at such places.

When a railway crosses any public road on a level, the spaces between the rails ought to be firmly paved level with their upper surface, to prevent carriages sustaining any shock when passing over it. In some instances we observe that each line is formed with a double rail, having a groove along the middle for the flange of the wheels to run along: this tends greatly to prevent that concussive motion which carriages are liable to on such crossings.

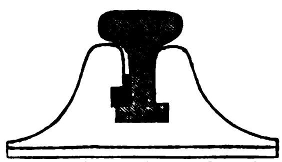
On the Manchester and Liverpool railway, each rail is five yards in length, and weighs thirty-five pounds per yard. The rails are supported every three feet upon stone blocks, two feet square by one in depth; but upon the embankments, where the foundations have not yet become stationary, oak transverse sleepers are used. Two holes, six inches deep and one inch in diameter, are drilled into each stone block, and into these are driven oak plugs; the cast-iron chairs to which the rails are immediately fastened, are then firmly spiked down to the oak

plugs; and a construction of great solidity and strength is thus obtained.



The opposite figure exhibits the mode of joining the rails to the chairs or pedestals, the lightly shaded part representing the form of the rails. In passing the bars through the rollers a lateral projection is rolled upon one side of each rail, parallel with its upper surface; and on one side of the cheek of each pedestal, a longitudinal cavity is cast equal in size with the projection, the section of which is represented in the above cut. A little higher, on the opposite side of each pedestal, another similar cavity is cast for the purpose of receiving an iron key; and when the rail is laid into the pedestal, by driving the key (shaded *dark*) into this cavity, it presses against the side of the rail, which forces the projecting part of the latter *home* into the opposite cavity, and thus effectually secures each rail from rising up.

The above method of Mr. Stephenson in fixing and securing the rails to the chairs is somewhat different from that of Mr. Losh, which is as follows: a projection is rolled on both sides of each rail, as shown in the subjoined section; that on the right side entering a cavity similar to the preceding plan. On the other cheek of the chair a longitudinal cavity is cast, to receive a key, but, as shown in the figure, it is a double one, acting at the same time upon the upper part of the projection on the rail, to force it down upon the chair, and against the side



of the rail, both to steady it and to force the projection on the opposite side of the rail into the cavity intended for it. By this mode of *keying*, if the rail works loose upon the chair, by driving the key it can again be tightened.

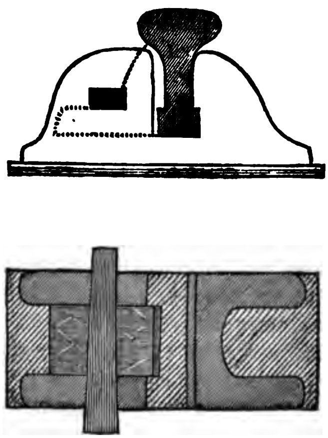
Parallel Rails. The late Mr. Steel, we believe, was the first who introduced the parallel malleable iron edge-rail, in the year 1829, when forming the Clarence Railway; that is to say, the first, excepting the introduction of the original flat and square bars. His rails have a projection rolled on both sides of them, but different in shape to those represented in the latter diagram—being circular.

On one cheek of the chair a cavity is cast, corresponding with the projecting part of the rail; the other being straight. The wedges used for fastening the rails are straight on that side which is placed against the cheek of the chair; the other side having a longitudinal circular cavity along the bottom, similar to the cavity in the chair. One wedge is used to each chair, which fills the *whole space* between the latter and the rail; and by driving the wedge *home*, it presses against the side of the rail, and forces its projecting part on the opposite side, into the place for receiving it; thus steadying the rails, and at the same time preventing them from rising up. The rails are four inches deep; the circular projection is one and a quarter inches in diameter; and each rail weighs thirty-two pounds per lineal yard.

We have already stated how essential it is that chairs should bear upon *all* their base; it is also necessary that the latter should not be too small, which is another principal cause of the evils mentioned in p. 155.

A very good form of chair, and improved method of keying, has recently been introduced upon some of the principal railways in the north of England; the dimensions of which are as follow:—base, nine inches in length; four and a quarter inches in breadth; and one and a quarter inch in thickness. The height of the chair is four inches; its sides and cheeks are one inch in thickness; and each chair weighs twenty pounds.

The subjoined drawing represents a horizontal section of the chair alluded to, at the level of the under side of the *rail*. One cheek of the chair corresponds with the form of the rail, similar to the preceding chairs; the other being *open* except for the distance of one inch at each side (the thickness of the side of the chair) as shown at the right side of the opposite drawing. A wedge of the form of an L—as shown by the dotted lines—is placed between the sides of the chair; its base occupying the whole breadth thereof; and its front similar to the opposite cheek of the chair. By pushing the wedge forward it comes in contact with the rail and forms one cheek of the chair. A hole, one and a quarter inch long, and three-fourths of an inch high,



is cast in the side of the chair (shaded dark in the upper diagram,) having another similar hole in the opposite side of the chair, through which a wrought-iron key is inserted. By driving the key it presses against the back of the perpendicular part of the wedge, and against the upper surface of its base, and forces the projection on one side of the rail into the cavity in the chair intended for it, and the other into a similar cavity in the front of the wedge; thus both effectually steadying the rails and preventing their rising up.

In some places we observe joint-chairs similar in shape to the preceding kind of chair, but of greater breadth—their base containing about fifty-five superficial inches each. These chairs weigh twenty-eight pounds each, and every one is secured to the block by *four* wooden pins. Indeed, on some railways, such chairs are now being used exclusively.

The plan of fastening the rails by keys is infinitely preferable to that by pins; on account of the latter soon becoming loose, and the difficulty of again securing them permanently. In some places we have observed keys securely fastened, merely by inserting a thin piece of wrought-iron between each key and the cheek of the chair, having its ends bent back at right-angles against the *ends* of the keys, thus forming a kind of clasp. This, although a very simple method, is nevertheless a very efficient one.

Continuous Bearings. Another mode of laying permanent roads, in England, has of late been adopted. We allude to the insertion of timber longitudinally underneath the iron rails; the latter being immediately attached to the former without the interposition of chairs. To the Americans, we believe, is due the honour of originally employing

iron and wooden bearers together in this manner; a method first introduced into this country by the engineer of the Great Western Railway.

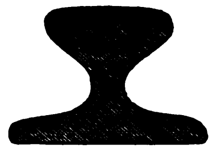
When permanent rails are supported at intervals only, it must be acknowledged that their rigidity is not equable; nor are they susceptible of that uniform smooth elasticity which appears to be the property of roads having a *continuous* bearing upon timber: we say *appears*, because from the recent introduction of the latter—sufficient time not yet having elapsed to allow *positive* judgment to be passed upon it. . . . . . .

We observe that the permanent rails on the Newcastle-upon-Tyne and North Shields Railway, are now being laid upon continuous timber bearings: they are composed of Memel timber, twelve inches in breadth, by six inches in depth; and transversely connected together every eight feet, by a piece of timber, containing about eighteen sectional inches. These cross-timbers are dove-tailed into the upper bed of the longitudinal bearers, their upper surfaces terminating *flush* with the upper surfaces of the latter: but upon the embankments, near Newcastle, transverse pieces of timber twelve inches by six are placed five feet apart underneath the longitudinal bearers.—The whole of the timbers have undergone the process of kyanizing.

Upon the middle of each longitudinal bearing is placed a strip of *felt** four inches in breadth, upon which are fixed the iron rails; the alternate sides of their base being screwed down to the timber at intervals of twenty inches: but at each end of every rail two screws are used.

* This material was manufactured by Messrs. Wm. and G. Borrodaill of London, and is well known by the name of "Borrodaill's Patent Felt:" it is generally considered superior to any other hitherto introduced, and is at present being used upon several railways.

The marginal sketch represents a section of the rails, which are of the following dimensions:—Four and one eighth inches in breadth, at the base; two and a quarter, on their upper surface; three quarters of an inch, where narrowest; and two and three quarter inches in height. The



rails were manufactured at the iron-works at Walker, near Newcastle-upon-Tyne; they are from twelve to fifteen feet in length, with square or butt joints; and each rail weighs fifty-three pounds per lineal yard.

CHAPTER XI.

EXCAVATION TABLES.

The following tables exhibit the number of cubic yards contained in a *chain in length*; the slopes or sides of the excavation (or embankment) being worked as follows:—Table first, batter of slopes, 1 horizontal to each perpendicular foot. Table second, batter of slopes, $1\frac{1}{4}$ to one. Table third, batter of slopes, $1\frac{1}{2}$ to one. Table fourth, batter of slopes, $1\frac{3}{4}$ to one. And table fifth, batter of slopes, 2 feet to each perpendicular foot.

The columns in *each* table represent the cubic yards contained in a *chain in length*; the breadths at the formation-level being 24, 27, 30, 33, and 36 feet respectively. The last column in each table shows the number of cubic yards contained in a chain in length and *one perpendicular foot* in breadth. It was considered unnecessary to insert any fractional parts in any of the tables except the last columns of each: in the other, where a fractional part was less than half a cubic yard, it has been omitted; and where it exceeded one-half, one cubic yard has been added to each integral quantity.

Should an excavation or embankment not correspond with any of the breadths in the tables, the cubic content may readily be found by adding to any sum opposite the quantity in the last column

for every foot in breadth that it differs from the table breadth. Thus, to find the cubic content of of a chain in length of cutting, 39 feet 9 inches deep; batter of slopes, one to one; and breadth at the formation-level or bottom of the cut, 28 feet?

In the first table

27 feet in breadth contains 6486
and one foot in breadth contains 97·17+
6583·17 cub. yds.

Again, to find the content of a chain in length of cutting 39 feet 9 inches deep; batter of slopes, one to one; and breadth at the formation-level, 35 feet? In the first table

36 feet in breadth contains......7360
and one foot in breadth contains 97·17—
7262·83 cub. yds.

TABLE 1.

Batter of Slopes, 1 Horizontal, to each Perpendicular Foot.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	6 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
1	0	61	68	76	83	90	2·44
1	3	77	86	96	105	114	3·06
1	6	94	105	116	127	138	3·67
1	9	110	123	136	149	162	4·28
2	0	127	142	156	171	186	4·89
2	3	144	161	177	194	210	5·50
2	6	162	180	199	217	235	6·11
2	9	180	200	220	240	260	6·72
3	0	198	220	242	264	286	7·33
3	3	217	240	264	288	312	7·94
3	6	235	261	287	312	338	8·55
3	9	254	282	309	337	364	9·17
4	0	274	303	332	362	391	9·78
4	3	293	325	356	387	418	10·39
4	6	314	347	380	413	446	11·
4	9	334	369	403	438	473	11·61
5	0	354	391	428	464	501	12·22
5	3	375	414	452	491	529	12·83
5	6	397	437	477	518	558	13·44
5	9	418	460	503	545	587	14·06
6	0	440	484	528	572	616	14·67
6	3	462	508	554	600	646	15·28
6	6	485	532	580	628	675	15·89
6	9	507	557	606	656	705	16·50

Batter of Slopes, 1 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
7	0	530	582	633	684	736	17·11
7	3	554	607	660	713	766	17·72
7	6	578	633	688	743	798	18·33
7	9	602	658	715	772	829	18·94
8	0	626	684	743	802	860	19·55
8	3	650	711	771	832	892	20·17
8	6	675	738	800	862	925	20·78
8	9	700	765	829	893	957	21·39
9	0	726	792	858	924	990	22·
9	3	752	820	887	955	1023	22·61
9	6	778	848	917	987	1057	23·22
9	9	804	876	947	1019	1090	23·83
10	0	831	904	978	1051	1124	24·44
10	3	858	933	1009	1084	1159	25·06
10	6	886	963	1040	1117	1194	25·67
10	9	913	992	1071	1150	1229	26·28
11	0	941	1022	1102	1183	1264	26·89
11	3	969	1052	1134	1217	1299	27·50
11	6	998	1082	1167	1251	1335	28·11
11	9	1027	1113	1199	1285	1371	28·72
12	0	1056	1144	1232	1320	1408	29·33
12	3	1086	1175	1265	1355	1445	29·94
12	6	1115	1207	1299	1390	1482	30·55
12	9	1145	1239	1332	1426	1519	31·17
13	0	1176	1271	1366	1462	1557	31·78
13	3	1206	1304	1401	1498	1595	32·39
13	6	1238	1337	1436	1535	1634	33·
13	9	1269	1370	1470	1571	1672	33·61

Batter of Slopes, 1 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
14	0	1300	1403	1506	1608	1711	34·22
14	3	1332	1437	1541	1646	1750	34·83
14	6	1365	1471	1577	1684	1790	35·44
14	9	1397	1505	1614	1722	1830	36·06
15	0	1430	1540	1650	1760	1870	36·67
15	3	1463	1575	1687	1799	1911	37·28
15	6	1497	1610	1724	1838	1951	37·89
15	9	1530	1646	1761	1877	1992	38·50
16	0	1564	1682	1799	1916	2034	39·11
16	3	1599	1718	1837	1956	2075	39·72
16	6	1634	1755	1876	1997	2118	40·33
16	9	1669	1791	1914	2037	2160	40·94
17	0	1704	1828	1953	2078	2202	41·55
17	3	1739	1866	1992	2119	2245	42·17
17	6	1775	1904	2032	2160	2289	42·78
17	9	1811	1942	2072	2202	2332	43·39
18	0	1848	1980	2112	2244	2376	44·
18	3	1885	2019	2152	2286	2420	44·61
18	6	1922	2058	2193	2329	2465	45·22
18	9	1959	2097	2234	2372	2509	45·83
19	0	1997	2136	2276	2415	2554	46·44
19	3	2035	2176	2318	2459	2600	47·06
19	6	2074	2217	2360	2503	2646	47·67
19	9	2112	2257	2402	2547	2692	48·28
20	0	2151	2298	2444	2591	2738	48·89
20	3	2190	2339	2487	2636	2784	49·50
20	6	2230	2380	2531	2681	2831	50·11
20	9	2270	2422	2574	2726	2878	50·72

Batter of Slopes, 1 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
21	0	2310	2464	2618	2772	2926	51·33
21	3	2351	2506	2662	2818	2974	51·94
21	6	2391	2549	2707	2864	3022	52·55
21	9	2432	2592	2751	2911	3070	53·17
22	0	2474	2635	2796	2958	3119	53·78
22	3	2515	2679	2842	3005	3168	54·39
22	6	2558	2723	2888	3053	3218	55·
22	9	2600	2767	2933	3100	3267	55·61
23	0	2642	2811	2980	3148	3317	56·22
23	3	2685	2856	3026	3197	3367	56·83
23	6	2729	2901	3073	3246	3418	57·44
23	9	2772	2946	3121	3295	3469	58·06
24	0	2816	2992	3168	3344	3520	58·67
24	3	2860	3038	3216	3394	3572	59·28
24	6	2905	3084	3264	3444	2623	59·89
24	9	2949	3131	3312	3494	3675	60·50
25	0	2994	3178	3361	3544	3728	61·11
25	3	3040	3225	3410	3595	3780	61·72
25	6	3086	3273	3460	3647	3834	62·33
25	9	3132	3320	3509	3698	3887	62·94
26	0	3178	3368	3559	3750	3940	63·55
26	3	3224	3417	3609	3802	3994	64·17
26	6	3271	3466	3660	3854	4049	64·78
26	9	3318	3515	3711	3907	4103	65·39
27	0	3366	3564	3762	3960	4158	66·
27	3	3414	3614	3813	4013	4213	66·61
27	6	3462	3664	3865	4067	4269	67·22
27	9	3510	3714	3917	4121	4324	67·83

Batter of Slopes, 1 *to* 1.

Depth of Cutting.		Breadth at Formation Level. 24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	One perpendclr foot in Breadth.
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
28	0	3559	3764	3970	4175	4380	68·44
28	3	3608	3815	4023	4230	4437	69·06
28	6	3658	3867	4076	4285	4494	69·67
28	9	3707	3918	4129	4340	4551	70·28
29	0	3757	3970	4182	4395	4608	70·89
29	3	3807	4022	4236	4451	4665	71·50
29	6	3858	4074	4291	4507	4723	72·11
29	9	3909	4127	4345	4563	4781	72·72
30	0	3960	4180	4400	4620	4840	73·33
30	3	4012	4233	4455	4677	4899	73·94
30	6	4063	4287	4511	4734	4958	74·55
30	9	4115	4341	4566	4792	5017	75·17
31	0	4168	4395	4622	4850	5077	75·78
31	3	4220	4450	4679	4908	5137	76·39
31	6	4274	4505	4736	4967	5198	77·
31	9	4327	4560	4792	5025	5258	77·61
32	0	4380	4615	4850	5084	5319	78·22
32	3	4434	4671	4907	5144	5380	78·83
32	6	4489	4727	4965	5204	5442	79·44
32	9	4543	4783	5024	5264	5504	80·06
33	0	4598	4840	5082	5324	5566	80·67
33	3	4653	4897	5141	5385	5629	81·28
33	6	4709	4954	5200	5446	5691	81·89
33	9	4764	5012	5259	5507	5754	82·50
34	0	4820	5070	5319	5568	5818	83·11
34	3	4877	5128	5379	5630	5881	83·72
34	6	4934	5187	5440	5693	5946	84·33
34	9	4991	5245	5500	5755	6010	84·94

Batter of Slopes, 1 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
35	0	5048	5304	5561	5818	6074	85·55
35	3	5105	5364	5622	5881	6139	86·17
35	6	5163	5424	5684	5944	6205	86·78
35	9	5221	5484	5746	6008	6270	87·39
36	0	5280	5544	5808	6072	6336	88·
36	3	5339	5605	5870	6136	6402	88·61
36	6	5398	5666	5933	6201	6469	89·22
36	9	5457	5727	5996	6266	6535	89·83
37	0	5517	5788	6060	6331	6602	90·44
37	3	5577	5850	6124	6397	6670	91·06
37	6	5638	5913	6188	6463	6738	91·67
37	9	5698	5975	6252	6529	6806	92·28
38	0	5759	6038	6316	6595	6874	92·89
38	3	5820	6101	6381	6662	6942	93·50
38	6	5882	6164	6447	6729	7011	94·11
38	9	5944	6228	6512	6796	7080	94·72
39	0	6006	6292	6578	6864	7150	95·33
39	3	6069	6356	6644	6932	7220	95·94
39	6	6131	6421	6711	7000	7290	96·55
39	9	6194	6486	6777	7069	7360	97·17
40	0	6258	6551	6844	7138	7431	97·78

TABLE 2.

Batter of Slopes, 1¼ Horizontal, to each Perpendicular Foot.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
1	0	62	69	76	84	91	2·44
1	3	78	87	96	106	115	3·06
1	6	95	106	117	128	139	3·67
1	9	112	125	138	151	163	4·28
2	0	130	144	159	174	188	4·89
2	3	147	164	180	197	213	5·50
2	6	166	184	202	221	239	6·11
2	9	184	205	225	245	265	6·72
3	0	204	226	248	270	292	7·33
3	3	223	247	271	294	318	7·94
3	6	243	268	294	320	345	8·55
3	9	263	290	318	345	373	9·17
4	0	284	313	342	372	401	9·78
4	3	305	336	367	398	429	10·39
4	6	326	359	392	425	458	11·
4	9	348	382	417	452	487	11·61
5	0	370	406	443	480	516	12·22
5	3	392	431	469	508	546	12.83
5	6	415	455	496	536	576	13·44
5	9	438	481	523	565	607	14·06
6	0	462	506	550	594	638	14·67
6	3	486	532	578	624	669	15·28
6	6	510	558	606	653	701	15·89
6	9	535	585	634	684	733	16·50

Batter of Slopes, 1¼ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
7	0	560	612	663	714	766	17·11
7	3	586	639	692	745	799	17·72
7	6	612	667	722	777	832	18·33
7	9	638	695	752	809	865	18·94
8	0	665	724	782	841	900	19·55
8	3	692	752	813	873	934	20·17
8	6	719	782	844	906	969	20·78
8	9	747	811	876	940	1004	21·39
9	0	776	842	908	974	1040	22·
9	3	804	872	940	1008	1075	22·61
9	6	833	903	972	1042	1112	23·22
9	9	862	934	1005	1077	1148	23·83
10	0	892	966	1039	1112	1186	24·44
10	3	922	998	1073	1148	1223	25·06
10	6	953	1030	1107	1184	1261	25·67
10	9	984	1063	1141	1220	1299	26·28
11	0	1015	1096	1176	1257	1338	26·89
11	3	1047	1129	1212	1294	1377	27·50
11	6	1079	1163	1247	1332	1416	28·11
11	9	1111	1197	1284	1370	1456	28·72
12	0	1144	1232	1320	1408	1496	29·33
12	3	1177	1267	1357	1447	1536	29·94
12	6	1211	1302	1394	1486	1577	30·55
12	9	1245	1338	1432	1525	1619	31·17
13	0	1279	1374	1470	1565	1660	31·78
13	3	1314	1411	1508	1605	1702	32·39
13	6	1349	1448	1547	1646	1745	33·
13	9	1384	1485	1586	1687	1788	33·61

Batter of Slopes, $1\frac{1}{4}$ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
14	0	1420	1523	1626	1728	1831	34·22
14	3	1457	1561	1666	1770	1874	34·83
14	6	1493	1599	1706	1812	1918	35·44
14	9	1530	1638	1746	1855	1963	36·06
15	0	1568	1678	1788	1898	2008	36·67
15	3	1605	1717	1829	1941	2053	37·28
15	6	1643	1757	1871	1984	2098	37·89
15	9	1682	1797	1913	2028	2144	38·50
16	0	1721	1838	1956	2073	2190	39·11
16	3	1760	1879	1999	2118	2237	39·72
16	6	1800	1921	2042	2163	2284	40·33
16	9	1840	1963	2086	2208	2331	40·94
17	0	1880	2005	2130	2254	2379	41·55
17	3	1921	2048	2174	2301	2427	42·17
17	6	1962	2091	2219	2347	2476	42·78
17	9	2004	2134	2264	2395	2525	43·39
18	0	2046	2178	2310	2442	2574	44·
18	3	2088	2222	2356	2490	2624	44·61
18	6	2131	2267	2402	2538	2674	45·22
18	9	2174	2312	2449	2587	2724	45·83
19	0	2218	2357	2496	2636	2775	46·44
19	3	2262	2403	2544	2685	2826	47·06
19	6	2306	2449	2592	2735	2878	47·67
19	9	2351	2495	2640	2785	2930	48·28
20	0	2396	2542	2689	2836	2982	48·89
20	3	2441	2589	2738	2886	3035	49·50
20	6	2487	2637	2787	2938	3088	50·11
20	9	2533	2685	2837	2989	3142	50·72

Batter of Slopes, 1½ to 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
21	0	2580	2734	2888	3042	3196	51·33
21	3	2626	2782	2938	3094	3250	51·94
21	6	2674	2831	2989	3147	3304	52·55
21	9	2722	2881	3041	3200	3360	53·17
22	0	2770	2931	3092	3254	3415	53·78
22	3	2818	2981	3144	3308	3471	54·39
22	6	2867	3032	3197	3362	3527	55·
22	9	2916	3083	3250	3417	3583	55·61
23	0	2966	3134	3303	3472	3640	56·22
23	3	3016	3186	3357	3527	3698	56·83
23	6	3066	3238	3411	3583	3755	57·44
23	9	3117	3291	3465	3639	3814	58·06
24	0	3168	3344	3520	3696	3872	58·67
24	3	3220	3397	3575	3753	3931	59·28
24	6	3271	3451	3631	3810	3990	59·89
24	9	3324	3505	3687	3868	4050	60·50
25	0	3376	3560	3743	3926	4110	61·11
25	3	3429	3615	3800	3985	4170	61·72
25	6	3483	3670	3857	4044	4231	62·33
25	9	3537	3726	3914	4103	4292	62·94
26	0	3591	3782	3972	4163	4354	63·55
26	3	3646	3838	4031	4223	4416	64·17
26	6	3700	3895	4089	4283	4478	64·78
26	9	3756	3952	4148	4344	4540	65·39
27	0	3812	4010	4208	4406	4604	66·
27	3	3868	4067	4267	4467	4667	66·61
27	6	3924	4126	4327	4529	4731	67·22
27	9	3981	4184	4388	4592	4795	67·83

Batter of Slopes, 1½ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
28	0	4038	4244	4449	4654	4860	68·44
28	3	4096	4303	4510	4717	4925	69·06
28	6	4154	4363	4572	4781	4990	69·67
28	9	4212	4423	4634	4845	5056	70·28
29	0	4271	4484	4696	4909	5122	70·89
29	3	4330	4545	4759	4974	5188	71·50
29	6	4390	4606	4822	5039	5255	72·11
29	9	4450	4668	4886	5104	5322	72·72
30	0	4510	4730	4950	5170	5390	73·33
30	3	4571	4793	5014	5236	5458	73·94
30	6	4632	4855	5079	5303	5526	74·55
30	9	4693	4919	5144	5370	5595	75·17
31	0	4755	4982	5210	5437	5664	75·78
31	3	4817	5046	5276	5505	5734	76·39
31	6	4880	5111	5342	5573	5804	77·
31	9	4943	5176	5409	5641	5874	77·61
32	0	5006	5241	5476	5710	5945	78·22
32	3	5070	5306	5543	5779	6016	78·83
32	6	5134	5372	5611	5849	6087	79·44
32	9	5199	5439	5679	5919	6159	80·06
33	0	5264	5506	5748	5990	6232	80·67
33	3	5329	5573	5816	6060	6304	81·28
33	6	5394	5640	5886	6131	6377	81·89
33	9	5460	5708	5955	6203	6450	82·50
34	0	5527	5776	6026	6275	6524	83·11
34	3	5594	5845	6096	6347	6598	83·72
34	6	5661	5914	6167	6420	6673	84·33
34	9	5728	5983	6238	6493	6748	84·94

Batter of Slopes, 1¼ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
35	0	5796	6053	6310	6566	6823	85·55
35	3	5865	6123	6382	6640	6899	86·17
35	6	5933	6194	6454	6714	6975	86·78
35	9	6003	6265	6527	6789	7051	87·39
36	0	6072	6336	6600	6864	7128	88·
36	3	6142	6408	6674	6939	7205	88·61
36	6	6212	6480	6747	7015	7283	89·22
36	9	6283	6552	6822	7091	7361	89·83
37	0	6354	6625	6896	7168	7439	90·44
37	3	6425	6698	6971	7245	7518	91·06
37	6	6497	6772	7047	7322	7597	91·67
37	9	6569	6846	7123	7400	7676	92·28
38	0	6642	6920	7199	7478	7756	92·89
38	3	6714	6995	7275	7556	7836	93·50
38	6	6788	7070	7352	7635	7917	94·11
38	9	6861	7146	7430	7714	7998	94·72
39	0	6936	7222	7508	7794	8080	95·33
39	3	7010	7298	7586	7873	8161	95·94
39	6	7085	7374	7664	7954	8243	96·55
39	9	7160	7451	7743	8034	8326	97·17
40	0	7236	7529	7822	8116	8409	97·78

TABLE 3.

Batter of Slopes, 1½ Horizontal, to each Perpendicular Foot.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
1	0	62	70	77	84	92	2·44
1	3	79	88	97	107	116	3·06
1	6	96	107	118	129	140	3·67
1	9	114	127	140	152	165	4·28
2	0	132	147	161	176	191	4·89
2	3	151	167	184	200	217	5·50
2	6	170	188	206	225	243	6·11
2	9	189	209	229	250	270	6·72
3	0	209	231	253	275	297	7·33
3	3	229	253	277	301	325	7·94
3	6	250	276	302	327	353	8·55
3	9	272	299	327	354	382	9·17
4	0	293	323	352	381	411	9·78
4	3	316	347	378	409	440	10·39
4	6	338	371	404	437	470	11·
4	9	361	396	431	466	501	11·61
5	0	385	422	458	495	532	12·22
5	3	409	448	486	525	563	12.83
5	6	434	474	514	555	595	13·44
5	9	459	501	543	585	627	14·06
6	0	484	528	572	616	660	14·67
6	3	510	556	602	647	693	15·28
6	6	536	584	632	679	727	15·89
6	9	563	613	662	712	761	16·50

Batter of Slopes, 1½ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
7	0	590	642	693	744	796	17·11
7	3	618	671	724	778	831	17·72
7	6	646	701	756	811	866	18·33
7	9	675	732	789	845	902	18·94
8	0	704	763	821	880	939	19·55
8	3	734	794	855	915	976	20·17
8	6	764	826	888	951	1013	20·78
8	9	794	858	922	987	1051	21·39
9	0	825	891	957	1023	1089	22·
9	3	856	924	992	1060	1128	22·61
9	6	888	958	1028	1097	1167	23·22
9	9	921	992	1064	1135	1207	23·83
10	0	953	1027	1100	1173	1247	24·44
10	3	987	1062	1137	1212	1287	25·06
10	6	1020	1097	1174	1251	1328	25·67
10	9	1054	1133	1212	1291	1370	26·28
11	0	1089	1170	1250	1331	1412	26·89
11	3	1124	1207	1289	1372	1454	27·50
11	6	1160	1244	1328	1413	1497	28·11
11	9	1196	1282	1368	1454	1540	28·72
12	0	1232	1320	1408	1496	1584	29·33
12	3	1269	1359	1449	1538	1628	29·94
12	6	1306	1398	1490	1581	1673	30·55
12	9	1344	1438	1531	1625	1718	31·17
13	0	1382	1478	1573	1668	1764	31·78
13	3	1421	1518	1615	1713	1810	32·39
13	6	1460	1559	1658	1757	1856	33·
13	9	1500	1601	1702	1802	1903	33·61

Batter of Slopes, 1½ to 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
14	0	1540	1643	1745	1848	1951	34·22
14	3	1581	1685	1790	1894	1999	34·83
14	6	1622	1728	1834	1941	2047	35·44
14	9	1663	1771	1879	1988	2096	36·06
15	0	1705	1815	1925	2035	2145	36·67
15	3	1747	1859	1971	2083	2195	37·28
15	6	1790	1904	2018	2131	2245	37·89
15	9	1834	1949	2065	2180	2296	38·50
16	0	1877	1995	2112	2229	2347	39·11
16	3	1922	2041	2160	2279	2398	39·72
16	6	1966	2087	2208	2329	2450	40·33
16	9	2011	2134	2257	2380	2503	40·94
17	0	2057	2182	2306	2431	2556	41·55
17	3	2103	2230	2356	2483	2609	42·17
17	6	2150	2278	2406	2535	2663	42·78
17	9	2197	2327	2457	2587	2717	43·39
18	0	2244	2376	2508	2640	2772	44·
18	3	2292	2426	2560	2693	2827	44·61
18	6	2340	2476	2612	2747	2883	45·22
18	9	2389	2527	2664	2802	2939	45·83
19	0	2438	2578	2717	2856	2996	46·44
19	3	2488	2629	2770	2912	3053	47·06
19	6	2538	2681	2824	2967	3110	47·67
19	9	2589	2734	2879	3023	3168	48·28
20	0	2640	2787	2933	3080	3227	48·89
20	3	2692	2840	2989	3137	3286	49·50
20	6	2744	2894	3044	3195	3345	50·11
20	9	2796	2948	3100	3253	3405	50·72

Batter of Slopes, 1½ to 1.

Depth of Cutting.		Breadth at Formation Level. 24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	One perpendclr foot in Breadth.
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
21	0	2849	3003	3157	3311	3465	51·33
21	3	2902	3058	3214	3370	3526	51·94
21	6	2956	3114	3272	3429	3587	52·55
21	9	3011	3170	3330	3489	3649	53·17
22	0	3065	3227	3388	3549	3711	53·78
22	3	3121	3284	3447	3610	3773	54·39
22	6	3176	3341	3506	3671	3836	55·
22	9	3232	3399	3566	3733	3900	55·61
23	0	3289	3458	3626	3795	3964	56·22
23	3	3346	3517	3687	3858	4028	56·83
23	6	3404	3576	3748	3921	4093	57·44
23	9	3462	3636	3810	3984	4158	58·06
24	0	3520	3696	3872	4048	4224	58·67
24	3	3579	3757	3935	4112	4290	59·28
24	6	3638	3818	3998	4177	4357	59·89
24	9	3698	3880	4061	4243	4424	60·50
25	0	3758	3942	4125	4308	4492	61·11
25	3	3819	4004	4189	4375	4560	61·72
25	6	3880	4067	4254	4441	4628	62·33
25	9	3942	4131	4320	4508	4697	62·94
26	0	4004	4195	4385	4576	4767	63·55
26	3	4067	4259	4452	4644	4837	64·17
26	6	4130	4324	4518	4713	4907	64·78
26	9	4193	4389	4585	4782	4978	65·39
27	0	4257	4455	4653	4851	5049	66·
27	3	4321	4521	4721	4921	5121	66·61
27	6	4386	4588	4790	4991	5193	67·22
27	9	4452	4655	4859	5062	5266	67·83

Batter of Slopes, 1½ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
28	0	4517	4723	4928	5133	5339	68·44
28	3	4584	4791	4998	5205	5412	69·06
28	6	4650	4859	5068	5277	5486	69·67
28	9	4717	4928	5139	5350	5561	70·28
29	0	4785	4998	5210	5423	5636	70·89
29	3	4853	5068	5282	5497	5711	71·50
29	6	4922	5138	5354	5571	5787	72·11
29	9	4991	5209	5427	5645	5863	72·72
30	0	5060	5280	5500	5720	5940	73·33
30	3	5130	5352	5574	5795	6017	73·94
30	6	5200	5424	5648	5871	6095	74·55
30	9	5271	5497	5722	5948	6173	75·17
31	0	5342	5570	5797	6024	6252	75·78
31	3	5414	5643	5872	6102	6331	76·39
31	6	5486	5717	5948	6179	6410	77·
31	9	5559	5792	6025	6257	6490	77·61
32	0	5632	5867	6101	6336	6571	78·22
32	3	5706	5942	6179	6415	6652	78·83
32	6	5780	6018	6256	6495	6733	79·44
32	9	5854	6094	6334	6575	6815	80·06
33	0	5929	6171	6413	6655	6897	80·67
33	3	6004	6248	6492	6736	6980	81·28
33	6	6080	6326	6572	6817	7063	81·89
33	9	6157	6404	6652	6899	7147	82.50
34	0	6233	6483	6732	6981	7231	83·11
34	3	6311	6562	6813	7064	7315	83·72
34	6	6388	6641	6894	7147	7400	84·33
34	9	6466	6721	6976	7231	7486	84·94

Batter of Slopes, 1½ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
35	0	6545	6802	7058	7315	7572	85·55
35	3	6624	6883	7141	7400	7658	86·17
35	6	6704	6964	7224	7485	7745	86·78
35	9	6784	7046	7308	7570	7832	87·39
36	0	6864	7128	7392	7656	7920	88·
36	3	6945	7211	7477	7742	8008	88·61
36	6	7026	7294	7562	7829	8097	89·22
36	9	7108	7378	7647	7917	8186	89·83
37	0	7190	7462	7733	8004	8276	90·44
37	3	7273	7546	7819	8093	8366	91·06
37	6	7356	7631	7906	8181	8456	91·67
37	9	7440	7717	7994	8270	8547	92·28
38	0	7524	7803	8081	8360	8639	92·89
38	3	7609	7889	8170	8450	8731	93·50
38	6	7694	7976	8258	8541	8823	94·11
38	9	7779	8063	8347	8632	8916	94·72
39	0	7865	8151	8437	8723	9009	95·33
39	3	7951	8239	8527	8815	9103	95·94
39	6	8038	8328	8618	8907	9197	96·55
39	9	8126	8417	8709	9000	9292	97·17
40	0	8213	8507	8800	9093	9387	97·78
40	3	8302	8597	8892	9187	9482	98·39
40	6	8390	8687	8984	9281	9578	99·
40	9	8479	8778	9077	9376	9675	99·61
41	0	8569	8870	9170	9471	9772	100·22
41	3	8659	8962	9264	9567	9869	100·83
41	6	8750	9054	9358	9663	9967	101·44
41	9	8841	9147	9453	9759	10065	102·06

Batter of Slopes, 1½ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
42	0	8932	9240	9548	9856	10164	102·67
42	3	9024	9334	9644	9953	10263	103·28
42	6	9116	9428	9740	10051	10363	103·89
42	9	9209	9523	9836	10150	10463	104·50
43	0	9302	9618	9933	10248	10564	105·11
43	3	9396	9713	10030	10348	10665	105·72
43	6	9490	9809	10128	10447	10766	106·33
43	9	9585	9906	10227	10547	10868	106·94
44	0	9680	10003	10325	10648	10971	107·55
44	3	9776	10100	10425	10749	11074	108·17
44	6	9872	10198	10524	10851	11177	108·78
44	9	9968	10296	10624	10953	11281	109·39
45	0	10065	10395	10725	11055	11385	110·
45	3	10162	10494	10826	11158	11490	110·61
45	6	10260	10594	10928	11261	11595	111·22
45	9	10359	10694	11030	11365	11701	111·83
46	0	10457	10795	11132	11469	11807	112·44
46	3	10557	10896	11235	11574	11913	113·06
46	6	10656	10997	11338	11679	12020	113·67
46	9	10756	11099	11442	11785	12128	114·28
47	0	10857	11202	11546	11891	12236	114·89
47	3	10958	11305	11651	11998	12344	115·50
47	6	11060	11408	11756	12105	12453	116·11
47	9	11162	11512	11862	12212	12562	116·72
48	0	11264	11616	11968	12320	12672	117·33
48	3	11367	11721	12075	12428	12782	117·94
48	6	11470	11826	12182	12537	12893	118·55
48	9	11574	11932	12289	12647	13004	119·17

Batter of Slopes, $1\frac{1}{2}$ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
49	0	11678	12038	12397	12756	13116	119·78
49	3	11783	12144	12505	12867	13228	120·39
49	6	11888	12251	12614	12977	13340	121·
49	9	11994	12359	12724	13088	13453	121·61
50	0	12100	12467	12833	13200	13567	122·22
50	3	12207	12575	12944	13312	13681	122·83
50	6	12314	12684	13054	13425	13795	123·44
50	9	12421	12793	13165	13538	13910	124·06
51	0	12529	12903	13277	13651	14025	124·67
51	3	12637	13013	13389	13765	14141	125·28
51	6	12746	13124	13502	13879	14257	125·89
51	9	12856	13235	13615	13994	14374	126·50
52	0	12965	13347	13728	14109	14491	127·11
52	3	13076	13459	13842	14225	14608	127·72
52	6	13186	13571	13956	14341	14726	128·33
52	9	13297	13684	14071	14458	14845	128·94
53	0	13409	13798	14186	14575	14964	129·55
53	3	13521	13912	14302	14693	15083	130·17
53	6	13634	14026	14418	14811	15203	130·78
53	9	13747	14141	14535	14929	15323	131·39
54	0	13860	14256	14652	15048	15444	132.

TABLE 3.

Batter of Slopes, 1¾ Horizontal, to each Perpendicular Foot.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
1	0	63	70	78	85	92	2·44
1	3	80	89	98	108	117	3·06
1	6	98	109	120	131	142	3·67
1	9	116	129	141	154	167	4·28
2	0	134	149	164	178	193	4·89
2	3	154	170	187	203	220	5·50
2	6	173	192	210	228	247	6·11
2	9	194	214	234	254	274	6·72
3	0	215	237	259	281	303	7·33
3	3	236	260	284	307	331	7·94
3	6	258	283	309	335	360	8·55
3	9	280	308	335	363	390	9·17
4	0	303	332	362	391	420	9·78
4	3	327	358	389	420	451	10·39
4	6	351	384	417	450	483	11·
4	9	375	410	445	480	515	11·61
5	0	400	437	474	510	547	12·22
5	3	426	464	503	541	580	12.83
5	6	452	492	533	573	613	13·44
5	9	479	521	563	605	647	14·06
6	0	506	550	594	638	682	14·67
6	3	534	580	625	671	717	15·28
6	6	562	610	657	705	753	15·89
6	9	591	640	690	739	789	16·50

Batter of Slopes, $1\frac{3}{4}$ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
7	0	620	672	723	774	826	17·11
7	3	650	703	757	810	863	17·72
7	6	681	736	791	846	901	18·33
7	9	712	768	825	882	939	18·94
8	0	743	802	860	919	978	19·55
8	3	775	836	896	957	1017	20·17
8	6	808	870	932	995	1057	20·78
8	9	841	905	969	1033	1098	21·39
9	0	875	941	1007	1073	1139	22·
9	3	909	977	1044	1112	1180	22·61
9	6	943	1013	1083	1152	1222	23·22
9	9	979	1050	1122	1193	1265	23·83
10	0	1014	1088	1161	1234	1308	24·44
10	3	1051	1126	1201	1276	1351	25·06
10	6	1088	1165	1242	1319	1396	25·67
10	9	1125	1204	1283	1362	1440	26·28
11	0	1163	1244	1324	1405	1486	26·89
11	3	1201	1284	1366	1449	1531	27·50
11	6	1240	1325	1409	1493	1578	28·11
11	9	1280	1366	1452	1538	1625	28·72
12	0	1320	1408	1496	1584	1672	29·33
12	3	1361	1450	1540	1630	1720	29·94
12	6	1402	1493	1585	1677	1768	30·55
12	9	1443	1537	1630	1724	1817	31·17
13	0	1486	1581	1676	1772	1867	31·78
13	3	1528	1626	1723	1820	1917	32·39
13	6	1572	1671	1770	1869	1968	33·
13	9	1615	1716	1817	1918	2019	33·61

Batter of Slopes, 1¾ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
14	0	1660	1762	1865	1968	2070	34·22
14	3	1705	1809	1914	2018	2123	34·83
14	6	1750	1856	1963	2069	2175	35·44
14	9	1796	1904	2012	2121	2229	36·06
15	0	1843	1953	2063	2173	2283	36·67
15	3	1890	2001	2113	2225	2337	37·28
15	6	1937	2051	2164	2278	2392	37·89
15	9	1985	2101	2216	2332	2447	38·50
16	0	2034	2151	2268	2386	2503	39·11
16	3	2083	2202	2321	2440	2560	39·72
16	6	2133	2254	2375	2496	2617	40·33
16	9	2183	2306	2429	2551	2674	40·94
17	0	2234	2358	2483	2608	2732	41·55
17	3	2285	2411	2538	2664	2791	42·17
17	6	2337	2465	2593	2722	2850	42·78
17	9	2389	2519	2649	2780	2910	43·39
18	0	2442	2574	2706	2838	2970	44·
18	3	2495	2629	2763	2897	3031	44·61
18	6	2549	2685	2821	2956	3092	45·22
18	9	2604	2741	2879	3016	3154	45·83
19	0	2659	2798	2938	3077	3216	46·44
19	3	2715	2856	2997	3138	3279	47·06
19	6	2771	2914	3057	3200	3343	47·67
19	9	2827	2972	3117	3262	3407	48·28
20	0	2884	3031	3178	3324	3471	48·89
20	3	2942	3091	3239	3388	3536	49·50
20	6	3000	3151	3301	3451	3602	50·11
20	9	3059	3211	3364	3516	3668	50·72

Batter of Slopes, 1¾ to 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
21	0	3119	3273	3427	3581	3735	51·33
21	3	3178	3334	3490	3646	3802	51·94
21	6	3239	3396	3554	3712	3869	52·55
21	9	3300	3459	3619	3778	3938	53·17
22	0	3361	3522	3684	3845	4006	53·78
22	3	3423	3586	3749	3913	4076	54·39
22	6	3486	3651	3816	3981	4146	55·
22	9	3549	3716	3882	4049	4216	55·61
23	0	3612	3781	3950	4118	4287	56·22
23	3	3676	3847	4017	4188	4358	56·83
23	6	3741	3913	4086	4258	4430	57·44
23	9	3806	3980	4155	4329	4503	58·06
24	0	3872	4048	4224	4400	4576	58·67
24	3	3938	4116	4294	4472	4650	59·28
24	6	4005	4185	4364	4544	4724	59·89
24	9	4072	4254	4435	4617	4798	60·50
25	0	4140	4324	4507	4690	4874	61·11
25	3	4209	4394	4579	4764	4949	61·72
25	6	4278	4465	4652	4839	5026	62·33
25	9	4347	4536	4725	4914	5102	62·94
26	0	4417	4608	4798	4989	5180	63·55
26	3	4488	4680	4873	5065	5258	64·17
26	6	4559	4753	4947	5142	5336	64·78
26	9	4630	4827	5023	5219	5415	65·39
27	0	4703	4901	5099	5297	5495	66·
27	3	4775	4975	5175	5375	5575	66·61
27	6	4848	5050	5252	5453	5655	67·22
27	9	4922	5126	5329	5533	5736	67·83

Batter of Slopes, 1¾ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
28	0	4996	5202	5407	5612	5818	68·44
28	3	5071	5278	5486	5693	5900	69·06
28	6	5147	5356	5565	5774	5983	69·67
28	9	5223	5433	5644	5855	6066	70·28
29	0	5299	5512	5724	5937	6150	70·89
29	3	5376	5590	5805	6019	6234	71·50
29	6	5453	5670	5886	6102	6319	72·11
29	9	5531	5750	5968	6186	6404	72·72
30	0	5610	5830	6050	6270	6490	73·33
30	3	5689	5911	6133	6355	6576	73·94
30	6	5769	5992	6216	6440	6663	74·55
30	9	5849	6074	6300	6525	6751	75·17
31	0	5930	6157	6384	6612	6839	75·78
31	3	6011	6240	6469	6698	6928	76·39
31	6	6093	6324	6555	6786	7017	77·
31	9	6175	6408	6641	6873	7106	77·61
32	0	6258	6492	6727	6962	7196	78·22
32	3	6341	6578	6814	7051	7287	78·83
32	6	6425	6663	6902	7140	7378	79·44
32	9	6510	6750	6990	7230	7470	80·06
33	0	6595	6837	7079	7321	7563	80·67
33	3	6680	6924	7168	7412	7655	81·28
33	6	6766	7012	7257	7503	7749	81·89
33	9	6853	7100	7348	7595	7843	82.50
34	0	6940	7189	7438	7688	7937	83·11
34	3	7027	7279	7530	7781	8032	83·72
34	6	7116	7369	7622	7875	8128	84·33
34	9	7204	7459	7714	7969	8224	84·94

Batter of Slopes, 1¾ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
35	0	7294	7550	7807	8064	8320	85·55
35	3	7383	7642	7900	8159	8417	86·17
35	6	7474	7734	7994	8255	8515	86·78
35	9	7565	7827	8089	8351	8613	87·39
36	0	7656	7920	8184	8448	8712	88·
36	3	7748	8014	8280	8545	8811	88·61
36	6	7840	8108	8376	8643	8911	89·22
36	9	7933	8203	8472	8742	9011	89·83
37	0	8027	8298	8570	8841	9112	90·44
37	3	8121	8394	8667	8941	9214	91·06
37	6	8216	8491	8766	9041	9316	91·67
37	9	8311	8588	8864	9141	9418	92·28
38	0	8406	8685	8964	9242	9521	92·89
38	3	8503	8783	9064	9344	9625	93·50
38	6	8599	8882	9164	9446	9729	94·11
38	9	8697	8981	9265	9549	9833	94·72
39	0	8795	9081	9367	9653	9939	95·33
39	3	8893	9181	9469	9756	10044	95·94
39	6	8992	9281	9571	9861	10150	96·55
39	9	9091	9383	9674	9966	10257	97·17
40	0	9191	9484	9778	10071	10364	97·78
40	3	9292	9587	9882	10177	10472	98·39
40	6	9393	9690	9987	10284	10581	99·
40	9	9494	9793	10092	10391	10690	99·61
41	0	9596	9897	10198	10498	10799	100·22
41	3	9699	10001	10304	10606	10909	100·83
41	6	9802	10106	10411	10715	11019	101·44
41	9	9906	10212	10518	10824	11130	102·06

Batter of Slopes, $1\frac{3}{4}$ *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
42	0	10010	10318	10626	10934	11242	102·67
42	3	10115	10425	10734	11044	11354	103·28
42	6	10220	10532	10843	11155	11467	103·89
42	9	10326	10639	10953	11266	11580	104·50
43	0	10432	10748	11063	11378	11694	105·11
43	3	10539	10856	11174	11491	11808	105·72
43	6	10647	10966	11285	11604	11923	106·33
43	9	10755	11075	11396	11717	12038	106·94
44	0	10863	11186	11508	11831	12154	107·55
44	3	10972	11297	11621	11946	12270	108·17
44	6	11082	11408	11734	12061	12387	108·78
44	9	11192	11520	11848	12176	12505	109·39
45	0	11303	11633	11963	12293	12623	110·
45	3	11414	11746	12077	12409	12741	110·61
45	6	11525	11859	12193	12526	12860	111·22
45	9	11638	11973	12309	12644	12980	111·83
46	0	11750	12088	12425	12762	13100	112·44
46	3	11864	12203	12542	12881	13220	113·06
46	6	11978	12319	12660	13001	13342	113·67
46	9	12092	12435	12778	13121	13463	114·28
47	0	12207	12552	12896	13241	13586	114·89
47	3	12322	12669	13015	13362	13708	115·50
47	6	12438	12787	13135	13483	13832	116·11
47	9	12555	12905	13255	13605	13956	116·72
48	0	12672	13024	13376	13728	14080	117·33
48	3	12790	13143	13497	13851	14205	117·94
48	6	12908	13263	13619	13975	14330	118·55
48	9	13026	13384	13741	14099	14456	119·17

Batter of Slopes, 1¾ to 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
49	0	13146	13505	13864	14224	14583	119·78
49	3	13265	13627	13988	14349	14710	120·39
49	6	13386	13749	14112	14475	14838	121·
49	9	13506	13871	14236	14601	14966	121·61
50	0	13628	13994	14361	14728	15094	122·22
50	3	13750	14118	14487	14855	15224	122·83
50	6	13872	14242	14613	14983	15353	123·44
50	9	13995	14367	14739	15112	15484	124·06
51	0	14119	14493	14867	15241	15615	124·67
51	3	14243	14618	14994	15370	15746	125·28
51	6	14367	14745	15122	15500	15878	125·89
51	9	14492	14872	15251	15631	16010	126·50
52	0	14618	14999	15380	15762	16143	127·11
52	3	14744	15127	15510	15893	16277	127·72
52	6	14871	15256	15641	16026	16411	128·33
52	9	14998	15385	15772	16158	16545	128·94
53	0	15126	15514	15903	16292	16680	129·55
53	3	15254	15644	16035	16425	16816	130·17
53	6	15383	15775	16167	16560	16952	130·78
53	9	15512	15906	16300	16695	17089	131·39
54	0	15642	16038	16434	16830	17226	132.

TABLE 5.

Batter of Slopes, 2 Horizontal, to each Perpendicular Foot.

Depth of Cutting.		Breadth at Formation Level.					One perpendicular foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
1	0	64	71	78	86	93	2·44
1	3	81	90	99	109	118	3·06
1	6	99	110	121	132	143	3·67
1	9	118	130	143	156	169	4·28
2	0	137	152	166	181	196	4·89
2	3	157	173	190	206	223	5·50
2	6	177	196	214	232	251	6·11
2	9	198	218	239	259	279	6·72
3	0	220	242	264	286	308	7·33
3	3	242	266	290	314	338	7·94
3	6	265	291	317	342	368	8·55
3	9	289	316	344	371	399	9·17
4	0	313	342	372	401	430	9·78
4	3	338	369	400	431	462	10·39
4	6	363	396	429	462	495	11·
4	9	389	424	459	493	528	11·61
5	0	416	452	489	526	562	12·22
5	3	443	481	520	558	597	12·83
5	6	471	511	551	592	632	13·44
5	9	499	541	583	626	668	14·06
6	0	528	572	616	660	704	14·67
6	3	558	603	649	695	741	15·28
6	6	588	636	683	731	779	15·89
6	9	619	668	718	767	817	16·50

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
7	0	650	702	753	804	856	17·11
7	3	682	735	789	842	895	17·72
7	6	715	770	825	880	935	18·33
7	9	748	805	862	919	976	18·94
8	0	782	841	900	958	1017	19·55
8	3	817	877	938	998	1059	20·17
8	6	852	914	977	1039	1101	20·78
8	9	888	952	1016	1080	1144	21·39
9	0	924	990	1056	1122	1188	22·
9	3	961	1029	1097	1164	1232	22·61
9	6	999	1068	1138	1208	1277	23·22
9	9	1037	1108	1180	1251	1323	23·83
10	0	1076	1149	1222	1296	1369	24·44
10	3	1115	1190	1265	1341	1416	25·06
10	6	1155	1232	1309	1386	1463	25·67
10	9	1196	1274	1353	1432	1511	26·28
11	0	1237	1318	1398	1479	1560	26·89
11	3	1279	1361	1444	1526	1609	27·50
11	6	1321	1406	1490	1574	1659	28·11
11	9	1364	1450	1537	1623	1709	28·72
12	0	1408	1496	1584	1672	1760	29·33
12	3	1452	1542	1632	1722	1812	29·94
12	6	1497	1589	1681	1772	1864	30·55
12	9	1543	1636	1730	1823	1917	31·17
13	0	1589	1684	1780	1875	1970	31·78
13	3	1636	1733	1830	1927	2024	32·39
13	6	1683	1782	1881	1980	2079	33·
13	9	1731	1832	1933	2033	2134	33·61

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
14	0	1780	1882	1985	2088	2190	34·22
14	3	1829	1933	2038	2142	2247	34·83
14	6	1879	1985	2091	2198	2304	35·44
14	9	1929	2037	2145	2254	2362	36·06
15	0	1980	2090	2200	2310	2420	36·67
15	3	2032	2143	2255	2367	2479	37·28
15	6	2084	2198	2311	2425	2539	37·89
15	9	2137	2252	2368	2483	2599	38·50
16	0	2190	2308	2425	2542	2660	39·11
16	3	2244	2363	2483	2602	2721	39·72
16	6	2299	2420	2541	2662	2783	40·33
16	9	2354	2477	2600	2723	2846	40·94
17	0	2410	2535	2660	2784	2909	41·55
17	3	2467	2593	2720	2846	2973	42·17
17	6	2524	2652	2781	2909	3037	42·78
17	9	2582	2712	2842	2972	3102	43·39
18	0	2640	2772	2904	3036	3168	44·
18	3	2699	2833	2967	3100	3234	44·61
18	6	2759	2894	3030	3166	3301	45·22
18	9	2819	2956	3094	3231	3369	45·83
19	0	2880	3019	3158	3298	3437	46·44
19	3	2941	3082	3223	3365	3506	47·06
19	6	3003	3146	3289	3432	3575	47·67
19	9	3066	3210	3355	3500	3645	48·28
20	0	3129	3276	3422	3569	3716	48·89
20	3	3193	3341	3490	3638	3787	49·50
20	6	3257	3408	3558	3708	3859	50·11
20	9	3322	3474	3627	3779	3931	50·72

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
21	0	3388	3542	3696	3850	4004	51·33
21	3	3454	3610	3766	3922	4078	51·94
21	6	3521	3679	3837	3994	4152	52·55
21	9	3589	3748	3908	4067	4227	53·17
22	0	3657	3818	3980	4141	4302	53·78
22	3	3726	3889	4052	4215	4378	54·39
22	6	3795	3960	4125	4290	4455	55·
22	9	3865	4032	4199	4365	4532	55·61
23	0	3936	4104	4273	4442	4610	56·22
23	3	4007	4177	4348	4518	4689	56·83
23	6	4079	4251	4423	4596	4768	57·44
23	9	4151	4325	4499	4674	4848	58·06
24	0	4224	4400	4576	4752	4928	58·67
24	3	4298	4475	4653	4831	5009	59·28
24	6	4372	4552	4731	4911	5091	59·89
24	9	4447	4628	4810	4991	5173	60·50
25	0	4522	4706	4889	5072	5256	61·11
25	3	4598	4783	4969	5154	5339	61·72
25	6	4675	4862	5049	5236	5423	62·33
25	9	4752	4941	5130	5319	5508	62·94
26	0	4830	5021	5212	5402	5593	63·55
26	3	4909	5101	5294	5486	5679	64·17
26	6	4988	5182	5377	5571	5765	64·78
26	9	5068	5264	5460	5656	5852	65·39
27	0	5148	5346	5544	5742	5940	66·
27	3	5229	5429	5629	5828	6028	66·61
27	6	5311	5512	5714	5916	6117	67·22
27	9	5393	5596	5800	6003	6207	67·83

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
28	0	5476	5681	5886	6092	6297	68·44
28	3	5559	5766	5973	6181	6388	69·06
28	6	5643	5852	6061	6270	6479	69·67
28	9	5728	5938	6149	6360	6571	70·28
29	0	5813	6026	6238	6451	6664	70·89
29	3	5899	6113	6328	6542	6757	71·50
29	6	5985	6202	6418	6634	6851	72·11
29	9	6072	6290	6509	6727	6945	72·72
30	0	6160	6380	6600	6820	7040	73·33
30	3	6248	6470	6692	6914	7136	73·94
30	6	6337	6561	6785	7008	7232	74·55
30	9	6427	6652	6878	7103	7329	75·17
31	0	6517	6744	6972	7199	7426	75·78
31	3	6608	6837	7066	7295	7524	76·39
31	6	6699	6930	7161	7392	7623	77·
31	9	6791	7024	7257	7489	7722	77·61
32	0	6884	7118	7353	7588	7822	78·22
32	3	6977	7213	7450	7686	7923	78·83
32	6	7071	7309	7547	7786	8024	79·44
32	9	7165	7405	7645	7886	8126	80·06
33	0	7260	7502	7744	7986	8228	80·67
33	3	7356	7599	7843	8087	8331	81·28
33	6	7452	7698	7943	8189	8435	81·89
33	9	7549	7796	8044	8291	8539	82·50
34	0	7646	7896	8145	8394	8644	83·11
34	3	7744	7995	8247	8498	8749	83·72
34	6	7843	8096	8349	8602	8855	84·33
34	9	7942	8197	8452	8707	8962	84·94

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
35	0	8042	8299	8556	8812	9069	85·55
35	3	8143	8401	8660	8918	9177	86·17
35	6	8244	8504	8765	9025	9285	86·78
35	9	8346	8608	8870	9132	9394	87·39
36	0	8448	8712	8976	9240	9504	88·
36	3	8551	8817	9083	9348	9614	88·61
36	6	8655	8922	9190	9458	9725	89·22
36	9	8759	9028	9298	9567	9837	89·83
37	0	8864	9135	9406	9678	9949	90·44
37	3	8969	9242	9515	9789	10062	91·06
37	6	9075	9350	9625	9900	10175	91·67
37	9	9182	9458	9735	10012	10289	92·28
38	0	9289	9568	9846	10125	10404	92·89
38	3	9397	9677	9958	10238	10519	93·50
38	6	9505	9788	10070	10352	10635	94·11
38	9	9614	9898	10183	10467	10751	94·72
39	0	9724	10010	10296	10582	10868	95·33
39	3	9834	10122	10410	10698	10986	95·94
39	6	9945	10235	10525	10814	11104	96·55
39	9	10057	10348	10640	10931	11223	97·17
40	0	10169	10462	10756	11049	11342	97·78
40	3	10282	10577	10872	11167	11462	98·39
40	6	10395	10692	10989	11286	11583	99·
40	9	10509	10808	11107	11405	11704	99·61
41	0	10624	10924	11225	11526	11826	100·22
41	3	10739	11041	11344	11646	11949	100·83
41	6	10855	11159	11463	11768	12072	101·44
41	9	10971	11277	11583	11890	12196	102·06

Batter of Slopes, 2 to 1.

Depth of Cutting. ft.	in.	Breadth at Formation Level. 24 feet. cube yds.	27 feet. cube yds.	30 feet. cube yds.	33 feet. cube yds.	36 feet. cube yds.	One perpendclr foot in Breadth cube yds.
42	0	11088	11396	11704	12012	12320	102·67
42	3	11206	11515	11825	12135	12445	103·28
42	6	11324	11636	11947	12259	12571	103·89
42	9	11443	11756	12070	12383	12697	104·50
43	0	11562	11878	12193	12508	12824	105·11
43	3	11682	12000	12317	12634	12951	105·72
43	6	11803	12122	12441	12760	13079	106·33
43	9	11924	12245	12566	12887	13208	106·94
44	0	12046	12369	12692	13014	13337	107·55
44	3	12169	12493	12818	13142	13467	108·17
44	6	12292	12618	12945	13271	13597	108·78
44	9	12416	12744	13072	13400	13728	109·39
45	0	12540	12870	13200	13530	13860	110·
45	3	12665	12997	13329	13660	13992	110·61
45	6	12791	13124	13458	13792	14125	111·22
45	9	12917	13252	13588	13923	14259	111·83
46	0	13044	13381	13718	14056	14393	112·44
46	3	13171	13510	13849	14189	14528	113·06
46	6	13299	13640	13981	14322	14663	113·67
46	9	13428	13770	14113	14456	14799	114·28
47	0	13557	13902	14246	14591	14936	114·89
47	3	13687	14033	14380	14726	15073	115·50
47	6	13817	14166	14514	14862	15211	116·11
47	9	13948	14298	14649	14999	15349	116·72
48	0	14080	14432	14784	15136	15488	117·33
48	3	14212	14566	14920	15274	15628	117·94
48	6	14345	14701	15057	15412	15768	118·55
48	9	14479	14836	15194	15551	15909	119·17

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds	cube yds.	cube yds.	cube yds
49	0	14613	14972	15332	15691	16050	119·78
49	3	14748	15109	15470	15831	16192	120·39
49	6	14883	15246	15609	15972	16335	121·
49	9	15019	15384	15749	16113	16478	121·61
50	0	15156	15522	15889	16256	16622	122·22
50	3	15293	15661	16030	16398	16767	122·83
50	6	15431	15801	16171	16542	16912	123·44
50	9	15569	15941	16313	16686	17058	124·06
51	0	15708	16082	16456	16830	17204	124·67
51	3	15848	16223	16599	16975	17351	125·28
51	6	15988	16366	16743	17121	17499	125·89
51	9	16129	16508	16888	17267	17647	126·50
52	0	16270	16652	17033	17414	17796	127·11
52	3	16412	16795	17179	17562	17945	127·72
52	6	16555	16940	17325	17710	18095	128·33
52	9	16698	17085	17472	17859	18246	128·94
53	0	16842	17231	17620	18008	18397	129·55
53	3	16987	17377	17768	18158	18549	130·17
53	6	17132	17524	17917	18309	18701	130·78
53	9	17278	17672	18066	18460	18854	131·39
54	0	17424	17820	18216	18612	19008	132·
54	3	17571	17969	18367	18764	19162	132·61
54	6	17719	18118	18518	18918	19317	133·22
54	9	17867	18268	18670	19071	19473	133·83
55	0	18016	18419	18822	19226	19629	134·44
55	3	18165	18570	18975	19381	19786	135·06
55	6	18315	18722	19129	19536	19943	135·67
55	9	18466	18874	19283	19692	20101	136·28

Batter of Slopes, 2 *to* 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth.
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
56	0	18617	19028	19438	19849	20260	136·89
56	3	18769	19181	19594	20006	20419	137·50
56	6	18921	19336	19750	20164	20579	138·11
56	9	19074	19490	19907	20323	20739	138·72
57	0	19228	19646	20064	20482	20900	139·33
57	3	19382	19802	20222	20642	21062	139·94
57	6	19537	19959	20381	20802	21224	140·55
57	9	19693	20116	20540	20963	21387	141·17
58	0	19849	20274	20700	21125	21550	141·78
58	3	20006	20433	20860	21287	21714	142·39
58	6	20163	20592	21021	21450	21879	143·
58	9	20321	20752	21183	21613	22044	143·61
59	0	20480	20912	21345	21778	22210	144·22
59	3	20639	21073	21508	21942	22377	144·83
59	6	20799	21235	21671	22108	22544	145·44
59	9	20959	21397	21835	22274	22712	146·06
60	0	21120	21560	22000	22440	22880	146·67
60	3	21282	21723	22165	22607	23049	147·28
60	6	21444	21888	22331	22775	23219	147·89
60	9	21607	22052	22498	22943	23389	148·50
61	0	21770	22218	22665	23112	23560	149·11
61	3	21934	22383	22833	23282	23731	149·72
61	6	22099	22550	23001	23452	23903	150·33
61	9	22264	22717	23170	23623	24076	150·94
62	0	22430	22885	23340	23794	24249	151·55
62	3	22597	23053	23510	23966	24423	152·17
62	6	22764	23222	23681	24139	24597	152·78
62	9	22932	23392	23852	24312	24772	153·39

Batter of Slopes, 2 to 1.

Depth of Cutting.		Breadth at Formation Level.					One perpendclr foot in Breadth
		24 feet.	27 feet.	30 feet.	33 feet.	36 feet.	
ft.	in.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.	cube yds.
63	0	23100	23562	24024	24486	24948	154·
63	3	23269	23733	24197	24660	25124	154·61
63	6	23439	23904	24370	24836	25301	155·22
63	9	23609	24076	24544	25011	25479	155·83
64	0	23780	24249	24718	25188	25657	156·44
64	3	23951	24422	24893	25365	25836	157·06
64	6	24123	24596	25069	25542	26015	157·67
64	9	24296	24770	25245	25720	26195	158·28
65	0	24469	24946	25422	25899	26376	158·89
65	3	24643	25121	25600	26078	26557	159·50
65	6	24817	25298	25778	26258	26739	160·11
65	9	24992	25474	25957	26439	26921	160·72
66	0	25168	25652	26136	26620	27104	161·33
66	3	25344	25830	26316	26802	27288	161·94
66	6	25521	26009	26497	26984	27472	162·55
66	9	25699	26188	26678	27167	27657	163·17
67	0	25877	26368	26860	27351	27842	163·78
67	3	26056	26549	27042	27535	28028	164·39
67	6	26235	26730	27225	27720	28215	165·
67	9	26415	26912	27409	27905	28402	165·61
68	0	26596	27094	27593	28092	28590	166·22
68	3	26777	27277	27778	28278	28779	166·83
68	6	26959	27461	27963	28466	28968	167·44
68	9	27141	27645	28149	28654	29158	168·06
69	0	27324	27830	28336	28842	29348	168·67
69	3	27508	28015	28523	29031	29539	169·28
69	6	27692	28202	28711	29221	29731	169·89
69	9	27877	28388	28900	29411	29923	170·50
70	0	28062	28576	29089	29602	30116	171·11

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